PATHOGENIC VARIABILITY IN *MELOIDOGYNE INCOGNITA* AND *MELOIDOGYNE JAVANICA* POPULATIONS AND THEIR INTERACTIONS

ABSTRACT

THESIS SUBMITTED FOR THE DEGREE OF

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IN

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ABSTRACT

Pathogenic variability exist in the common species of root-knot nematodes. Host races (races) have been differentiated in *Meloidogyne incognita, M. arenaria* and *M. chitwoodi* populations in some countries of the world, based on their pathogenicity on specific host differentials. Pathogenic variability is, however, not fully recognised in *M. javanica* populations. Therefore, no races have been designated in its populations. Race characterization of populations of common root-knot nematode species is imperative for successful cultivation of vegetables in view of race-specific resistance reported in some vegetables. Therefore, populations of root-knot nematodes infecting vegetable crops were collected from nine districts of Uttar Pradesh, namely Almora, Pauri Garhwal, Dehradun (Hilly region); Farrukhabad, Hardoi, Sitapur (Central region); Basti, Gorakhpur, Deoria (Eastern region). Localities with extensive vegetable cultivations in each district were surveyed and root samples of vegetable crops like pepper, eggplant, tomato, okra, cucumber, cauliflower and cabbage were collected from different localities of the districts. Incidence and intensity of root-knot disease on vegetable crops were also assessed. The populations of root-knot nematodes were analysed to establish the identity of species and pathogenic variability was determined to differentiate races in the populations of the species. The cultivars of seven vegetable crops were screened against races of *M. incognita* and *M. javanica*, the commonly occurring species of the area. In addition, interspecific interaction of races of *M. incognita* (races 1 and 2) and two newly designated races of *M. javanica* (races A and B), the two most frequent species occurring in mixed populations, were investigated on okra.

Incidence and intensity of the disease

In general, a high percentage of fields grown with vegetables in the

area were found infested with root-knot nematodes. It emerged from the data that overall incidence of the disease on the vegetable crops was relatively high. In all the 9 districts more than 50% of the fields were infested and more than 36% root samples of the vegetable crops were infected with root-knot nematodes. The incidence of disease in vegetable fields was highest in Farrukhabad district (57.89%) and lowest in Pauri Garhwal (44%). Frequency of disease on root samples was also highest in Farrukhabad district (41.34%) and lowest incidence (28.97%) was recorded in Almora district.

Among the crops, the disease was highest on eggplant (59.79%), followed by tomato (40.63%), pepper (33.81%), okra (27.70%), cucumber (24.11%), cauliflower (14.11%) and cabbage (13.55%) in this order.

Intensity of the disease on the basis of gall index (GI) and egg mass index (EMI) on different vegetable crops showed wide variations. Based on mean GI/EMI, the intensity ranged from mild to severe. Among the vegetable crops, intensity was high on eggplant, pepper, tomato, okra and cucumber. On cabbage and cauliflower, the disease intensity was low. Poor root galling and infrequent egg mass production were noticed on these two crops.

Identity of the species

All the four major species of *Meloidogyne* viz., *Meloidogyne incognita*, *Meloidogyne javanica*, *Meloidogyne arenaria* and *Meloidogyne hapla*, were found to exist in the area. *M. incognita*, *M. javanica*, *M. arenaria* were encountered in all the districts. *M. hapla* was restricted to the hilly districts (Almora, Pauri Garhwal and Dehradun) of the study area. *M. incognita* was most frequent species in all the districts. Regardless of single or mixed infection, it was present in 69.57%

root samples. *M. javanica* was present in 50.43% and *M. arenaria* in 30.60% root samples, while *M. hapla* was found only in 9.57% of root samples. Frequency of single populations (49.74%) of all the species was slightly lower than mixed populations (50.26%). Among the mixed populations of different combinations of species, *M. incognita* + *M. javanica* combination was most frequent, followed by mixed populations of *M. incognita* + *M. javanica* + *M. arenaria* and *M. incognita* + *M. arenaria*.

Pathogenic variability in populations and identity of the races

All the four races of *M. incognita* (races 1, 2, 3 and 4) were recorded in the study area. Races 1, 2 and 4 were present in all the districts except race 4 in Sitapur district. However, race 3 was present only in six districts (Farrukhabad, Hardoi, Sitapur, Basti Gorakhpur and Deoria). Among the races of *M. incognita*, race 1 was most frequent followed by race 2, race 3 and race 4. The per cent occurrence of races in the area was 44.96, 31.20, 12.78 and 11.06 for race 1, race 2, race 3 and race 4, respectively.

In *M. arenaria* populations only race 2 was found invariably in all the districts. Race 1 was not found in any population of *M. arenaria*. Consequently, the frequency of race 2 in *M. arenaria* populations was 100%. Its highest frequency was in Sitapur district (24.07%) and lowest in Almora district (6.70%).

In *M. javanica,* two types of populations showing pathogenic variability were detected on the basis of their reactions on pepper cultivars, California Wonder and Suryamukhi Green. *M. javanica* populations that infected Suryamukhi Green but not California Wonder were designated as race A and the populations which infected both the cultivars were designated as race B. These two populations showing difference in their pathogenicity on these specific pepper cultivars are possibly distinct host races. These designations of races are, however, tentative and frurther studies are required for confirmation. Race A of *M. javanica* was more frequent than race B in all the districts in the area. Their frequencies were 70% and 30%, respectively. Among the districts, race A was highest in Sitapur followed by Gorakhpur, Basti, Hardoi, Farrukhabad, Deoria, Pauri Garhwal, Dehradun and Almora. Race B was also highest in Sitapur followed by Gorakhpur, Hardoi, Basti, Farrukhabad, Deoria, Dehradun, Pauri Garhwal and Almora.

Response of cultivars of vegetables

Ten cultivars of each vegetables namely pepper, eggplant, tomato, okra, cucumber, cauliflower and cabbage were screened against races 1-4 of *M. incognita* and two newly and tentatively designated races of *M. javanica* in artificial inoculations to evaluate their degree of resistance and host suitability designations (resistance) were assigned to the cultivars according to modified Canto-Saenz scheme. All the cultivars of eggplant, okra and most of the cultivars of cucumber screened were susceptible to all the test nematodes. On the other hand, some cultivars of pepper, tomato, cauliflower, and cabbage showed resistance to one or other test nematode. Two cultivars of pepper namely Ruby King and Chilli J-218 were resistant/immune to all the test nematodes. Cultivars King of North and Golden Queen were hypersusceptible to race 1 and race 2 of *M. incognita*. Cultivars Patna Red, NP-34, Yolo Wonder and Capsicum F-1 Bharat were resistant/immune to race A and race B of *M. javanica*. Rest of the cultivars were susceptible to all the four races of *M. incognita* and two races of *M. javanica*.

In tomato, one cultivar. S-120 was resistant and 9 cultivars were either susceptible or hypersusceptible to all the test nematodes. In cucumber, Improved Long Green alone showed resistance to both races of *M. javanica* while it was susceptible to all the four races of *M. incognita.* Cultivar All Season was hypersusceptible to all the test nematodes. Remaining cultivars were found to be susceptible to all the test nematodes. Among cauliflower cultivars screened, only Bharat Ratna and 96-D were resistant and immune respectively to all the races of *M. incognita* and *M. javanica.* Cultivar Vishwa Bharti was resistant to races 1, 2 and 4 and hypersusceptible to race 3 of *M. incognita* and races A and B of *M. javanica.* Other cultivars were either susceptible or hypersusceptible to all the test nematodes. A single cultivar of cabbage Early Queen was resistant to all the races of both species. Rest of the cultivars tested were either susceptible or hypersusceptible to the test nematodes.

Interspecific interaction

Interspecific interactions of race A and race B of *M. javanica* with race 1 and race 2 of *M. incognita* were studied separately in artificial inoculations on okra cv. Pusa Sawani. Mutual inhibitory interaction occurred between *M. javanica* and *M. incognita*, regardles of races involved. The races of *M. javanica* and *M. incognita* singly or concomitantly, significantly reduced plant growth of okra. The reductions in plant growth caused by single species inoculation (Pi = 1000 or 2000 J2) or by concomitant inoculation (Pi = 1000 + 1000 J2) of the species were not significantly different in general. However, the per cent reduction in plant growth caused by *M. javanica* race A was highest followed by *M. incognita* race 1, race 2 and *M. javanica* race B. The interspecific interaction of race A and race B of *M. javanica* with race 1 and race 2 of *M. incognita* influenced the root galling and egg mass production. The mean GI and EMI values were reduced in their concomitant presence.

Number of mature females, total population and reproduction factor of each species, irrespective of races were reduced in concomitant inoculations. The species suppressed each other when present on the same root system. The reductions in number of mature females/root system of race 1 and race 2 of *M. incognita* were greater than *M. javanica* race A but less than *M. javanica* race B. Among the races of *M. incognita* and *M. javanica*, the per cent reductions were lowest for race A of *M. javanica* (28.35%), followed by *M. incognita* race 1 (33.38%), *M. incognita* race 2 (35.15%) and *M. javanica* race B (40.50%). Interaction of race A and race B of *M. javanica* and race 1 and race 2 of *M. incognita* also influenced the total population. The total population was reduced by their concomitant presence when compared to the total population obtained in single species inoculation of *M. javanica* race A and race B or either race 1 and race 2 of *M. incognita* at the same level. The Rf value also declined in their interactions. It emerged, therefore, that *M. javanica* race A has better competitive ability than races 1 and 2 of *M. incognita* and race B of *M. javanica* and can be more damaging than other common races of *M. incognita* and *M. javanica*.

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1997

To my loving elder brother,

Mr. Muqeet A. Khan

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Dated November 21, 1997

CERTIFICATE

This is the certify that ***Mr. Badshah Khan*** has worked in this department as a research scholar under my guidance. His work on **Pathogenic variability in *Meloidogyne incognita* and *Meloidogyne javanica* populations and their interactions** is original and upto-date. He is allowed to submit this thesis for consideration of the award of the degree of **Doctor of Philosophy** in Agriculture (Nematology).

November 21, 1997

M. Wajid Khan
RESEARCH SUPERVISOR

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Badshah Khan

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INTRODUCTION

Root-knot nematodes, *Meloidogyne* species, one of the most important group of plant-parasitic nematodes, are world-wide in distribution. Every kind of cultivated and wild plants are parasitized by one or the other species of root-knot nematodes. All food and fibre yielding crops are attacked by them. At present 79 species have been described in the genus. The species of root-knot nematodes differ in their relative importance in agriculture, distribution and host range. Four species namely *Meloidogyne incognita* (Kofoid and White) Chitwood, *M. javanica* (Treub) Chitwood, *M. arenaria* (Neal) Chitwood and *M. hapla* Chitwood are called as major root-knot nematode species because of their wide distribution, extensive host range and damage potential for agricultural crops (Sasser, 1980; Sasser and Carter, 1982; Taylor, 1987). *M. incognita* and *M. javanica* are more widely distributed and of common occurrence than other two species. Average crop yield losses are estimated to be about 25% with damage in individual fields ranging as high as 60 per cent in areas where no control measures are adopted (Sasser, 1980; Sasser and Carter, 1982).

Sedentary females of root-knot nematodes as obligate parasites establish very specific, specialized and advanced type of host-parasite relationship and cause extensive damage to host crops. As these four major species widely occur under varied climates and agro-ecological conditions and show wide host range, ample opportunity exists for them to develop pathogenic variability in their populations. Four host races have been recognized in *M. incognita* and two in *M. arenaria* (Sasser, 1980). They have been found to be distributed in various parts of the world though pattern of their distribution and relative dominance varies (Khan and Khan, 1991a). Even though *M. javanica* is widely distributed like

M. incognita, existence of host races has not been established in its populations as yet. However, some indications of existence of host races in *M. javanica* populations have been provided by the reports of Stephan (1988), Rammah and Hirschmann (1990), Khan and Khan (1991b) and Patel *et al.* (1993).

Information on pathogenic variability in populations of *M. incognita* and *M. javanica* is of fundamental importance for their management particularly by the use of host resistance. Recent studies of Khan and Khan (1991b, 1991c, 1991d) showed that resistance in crop cultivars may be race-specific. Therefore, determination of races in the populations of *M. incognita* and *M. javanica*, the two most common species, is essential for ensuring the resistance response of the cultivar and root-knot free crops.

Till 1986, in India, occurrence of twelve species of root-knot nematodes were reported (Sitaramaiah, 1984; Nayak, *et al.* 1986). Three species namely *M. acrita*, *M. thamesi* and *M. lucknowica* were synonymized with *M. incognita*, *M. arenaria* and *M. javanica*, respectively (Eisenback and Triantaphyllou, 1991). In 1993, *M. triticoryzae* was added to the species index of the country (Gaur *et al.*, 1993). In total, 10 valid species are now recognised to exist in the country. Of these two species viz., *M. incognita* and *M. javanica* are predominant (Khan and Khan, 1990a). Like other parts of the world, major species of root-knot nematodes occur in mixed populations in the fields in India too. At the same time populations of same species may have distinct host races. A species population may have a mixture of host races. Such a situation causes difficulty and complicates the efforts for the management of the nematodes. India has a long history of agriculture, varied climates and agro-ecological zones and different cropping patterns.

This provides great opportunity for origin of host races among the populations of root-knot nematodes due to selection pressure. Occurrence of distinct host races has been reported in M. *incognita* from 15 states and in *M. arenaria* from one state of the country. All the 4 races in *M. incognita* and race 2 in *M. arenaria* are known to occur on a variety of crops.

In Uttar Pradesh, all the 4 major species of root-knot nematodes, *M. incognita, M. javanica, M. arenaria,* and *M. hapla* occur on several host plants (Verma and Singh, 1983; Sitaramaiah and Vishwakarma, 1978; Mathur and Varaprasad 1978; Khan *et al.*, 1984; Prakash, 1983; Verma, 1987; Khan and Khan, 1985; Haider and Khan, 1986a, 1986b). Recent studies of Khan (1988), Haider (1989) and Khan and Khan (1990a, 1991a, 1992) showed that *M. incognita* and *M. javanica* are almost equally frequent in several districts of the state. Occurrence of the 4 races in *M. incognita* and race 2 in *M. arenaria* populations in the state was also reported by Khan and Khan (1991a). No report, however, is available to show existence of races in *M. javanica* populations.

A perusal of literature on researchers emanating from different parts of the world, in general gives an impression that there is no race in *M. javanica*. Apparently, it seems that no attempt was made to ascertain the identity of races in *M. javanica*. Some reports, however, indicate towards the possible existence of host races in *M. javanica* population. Stephan (1988) predicted the existence of races in *M. javanica*. Recent studies (Khan, 1988; Haider, 1989; Rammah and Hirschmann, 1990; Khan and Khan 1991b) showed variations in pathogenicity of different populations of *M. javanica* on pepper cultivars. These studies indicated that pathogenic variability exists in *M. javanica* populations. But host races are well recognised only in *M. incognita, M. arenaria* and *M. chitwoodi* populations in different parts of the world (Sasser, 1980; Santo and Pinkerton, 1985; Khan and Khan, 1991a).

Uttar Pradesh, being a large state, has a varied climate, different kinds of agricultural soils and cropping patterns, extensive and intensive cultivation of field crops and practice of continous use of resistant crop cultivars. Possibility of variations within populations of *M. incognita* and *M. javanica*, the two most common species of the state, therefore, exists. In order to develop effective and efficient management systems for these two common species, there is an urgent need to analyse distribution and occurrence of host races in *M. incognita* and *M. javanica* populations. Some effort has been made in this direction particularly for *M. incognita*. Analysis of *M. javanica* population in the state for existence of host races is also needed for successful cultivation of crops.

Responses of host cultivars, being grown in different states of India, to species and races of *Meloidogyne* spp. known to exist in the state or country have not been properly and adequately ascertained and it demands sufficient study. Commercial cultivars being grown by farmers and the new cultivars before introduction have not been screened against all the four major species and known races of *Meloidogyne incognita* and *M. arenaria*. Before recommending cultivars for commercial cultivation, information regarding their performance against different species and races of *Meloidogyne* is necessary and should be provided to growers. Evaluation of resistance in some cultivars of tomato, eggplant, pepper, okra, cucumber, cauliflower, cabbage, etc. against the species and races of root-knot nematodes had been done in India (Khan and Khan 1989b, 1990b 1991b, 1991c, 1991d), but very few cultivars showed resistance.

Interactions between different species of plant parasitic nematodes differing in their modes of parasitism have been studied (Norton, 1978; Khan, 1981; Khan, 1984; Eisenback, 1985; Eisenback and Griffin, 1987). Results of such studies show that population of one or the other species of the interacting nematodes is generally increased or decreased. Gause's principle (Gause, 1934) or the principle of competitive exclusion states that one species eventually occupy the niche. In other words, if two species occupy it, one eventually will out-compete the other eventhough each species by itself can function in the niche. Norton (1978) concluded that competition between species of nematodes exists and is possible that some nematodes species are not able to compete with other species. Studies on interaction between species of root-knot nematodes are scarce though root-knot nematodes are commonly found in mixed populations (Taylor, 1987). Khan (1988), in his study on the identity and distribution of root-knot nematodes associated with vegetables, demonstrated that in many fields in the area of his study, mixed populations of *Meloidogyne* spp. were frequently present. A few attempts to study interactions between the species of *Meloidogyne* have, however, been made (Chapman, 1965; Johnson and Nusbaum 1970; Kinloch and Allen 1972). Since the establishment of races in some species of *Meloidogyne*, only few studies on interaction of races of *Meloidogyne* spp. on crop plants have been undertaken (Haider, 1989; Haider and Khan, 1993).

The synergistic or antagonistic relationships that may develop between different species of *Meloidogyne* and races in mixed populations need to be investigated. Relative dominance of different species and races of *Meloidogyne* on common hosts crops and their cultivars should be known. On this basis, the trend in population build-up and extent of crop losses can be envisaged. In view of the above, the following major aspects divided into three sections have been studied for Ph.D.

Section I

1. Survey of certain districts of Uttar Pradesh to collect root-knot nematodes from vegetable fields and observation of incidence and intensity of the root-knot disease on vegetable crops.

2. Identification of the species of the root-knot nematodes collected during the survey and maintenance of different populations in single egg mass cultures.

3. Identification of races of *M. incognita* and *M. arenaria* through host differential tests.

4. Differentiation of races in all *M. javanica* populations through the responses of resistant (California Wonder) and susceptible (Suryamukhi Green) cultivars of pepper.

Section II

5. Reaction of cultivars of some vegetable crops to different races of *M. incognita* and *M. javanica* identified.

Section III

6. Interactions of race 1 and race 2 of *M. incognita* with races of *M. javanica,* if any.

The above three aspects are presented in three independent sections in the thesis, each with separate literature review, materials and methods, results, discussion and summary. The literature cited has, however, been presented jointly for all three sections at the end.

SECTION - I

Distribution and Identity Studies

LITERATURE REVIEW

Root-knot nematodes (*Meloidogyne* spp.) attack an array of plants including all major crops across the world. They are destructive plant pathogens and cause substantial reduction in crop yield. Plant parasitic nematodes in general are estimated to cause 12% average annual yield loss based on calculations of damages caused to various world's major crops (Sasser, 1987). Root-knot nematodes rank first in among the plant parasitic nematodes in relation to yield losses and average crop yield losses due to them is about 5% on world-wide basis (Sasser and Carter, 1985). Root-knot nematodes were first recognised on glasshouse cucumbers in England by Berkeley (1855). Root-knot nematodes were known by different names for an extended period of time. Goeldi (1887) gave the present day name *Meloidogyne*. Species of root-knot nematodes are presently assigned to the genus *Meloidogyne* and till date about 79 species are described under the genus. As these nematodes are of great agricultural importance and world-wide in distribution, an international project called International *Meloidogyne* Project (IMP) funded by USAID was started in 1975 with its headquarter at the Department of Plant Pathology, North Carolina State University, Raleigh, USA to investigate the various aspects of the nematodes and the problems they cause to agricultural crops. A large number of nematologists from almost all over the world were associated with the project. The studies carried out under the aegis of the project showed that four species, *Meloidogyne incognita, M. javanica, M. arenaria, M. hapla* are major root-knot nematode species. These species comprised about 95% of total *Meloidogyne* populations obtained from different countries of the world and analysed at the IMP headquarter at Raleigh. Four races (race 1, race 2, race 3, and race 4) in *M. incognita* populations, and two races (race 1 and race 2) in *M. arenaria* populations were also identified (Carter and Sasser, 1982). Analysis of relationships between the occurrence of species and climatic and soil factors showed that *M. incognita, M. javanica* and *M. arenaria* were found to be distributed largely in areas with average annual temperatures between 15° and 33°C. *M. hapla* and *M. chitwoodi* were found frequently in areas with average annual temperatures of less than 15°C. In general, root-knot nematodes occurred most frequently in soil with less than 10% clay, less than 30% silt, and atleast 60% sand. The analysis, however, showed that basically, root-knot nematodes occurred anywhere their host plants grow.

Several species of *Meloidogyne* occur in India on a variety of crops. Until 1977, *M. incognita, M. javanica, M. hapla, M. indica, M. lucknowica, M. brevicauda, M. thamesi* and *M. graminicola* were known to exist in the country (Sasser, 1977). Till 1986 twelve species of *Meloidogyne* viz. *M. incognita, M. javanica, M. arenaria, M. hapla, M. graminicola, M. lucknowica, M. acrita, M. brevicauda, M. africana, M. exigua, M. thamesi* and *M. graminis* were mentioned attacking a large number of host plants in India (Sitaramaiah, 1984; Nayak *et al.* 1986). Recently, a new species of root-knot nematode, *M. triticoryzae* was reported (Gaur *et al.*, 1993). On differentiation of races in *M. incognita* and *M. arenaria*, there are a few reports (Krishnappa, 1985; Khan, 1988; Haider, 1989; Khan *et al.*, 1988; Khan and Khan, 1991a) (Table 1).

Out of 26 states and 5 union territories in India occurrence of root-knot nematodes is recorded from 22 states and their races from 15 states. In the state of Andhra Pradesh, Srinivasan and D'Souza (1965) recorded *M. exigua* on *Bidens pilosa*. Singh *et al.* (1979) found in a survey that root-knot nematode was widely distributed on citrus roots.

Table 1. Species and races of root-knot nematodes (*Meloidogyne* species) recorded in India

Species	Races
M. incognita	1, 2, 3, 4
M. javanica	-*
M. arenaria	2
M. hapla	-
M. graminicola	-
M. exigua	-
M. africana	-
M. brevicauda	-
M. graminis	-
M. triticoryzae	-

* Race does not exist

However, species was not identified by them. Krishnappa (1982) detected *M. incognita* race 1 from the state. *M. incognita* has been found on potato in Itanagar of Arunachal Pradesh (Mishra and Jayaprakash, 1980). *M. graminicola* is reported to occur on rice in Assam (Roy, 1973). *M. incognita* was highly frequent in two jute growing districts of Assam (Bora and Phukan, 1986). Sharma *et al.* (1989) recorded *M. incognita* race 1 and 2 on vegetables from the state. Nirula and Kumar (1964, 1966) identified *M. incognita* and *M. javanica* infecting various kinds of plants in Northern India especially from Patna (Bihar) and Shimla (Himachal Pradesh). *M. incognita, M. arenaria* and *M. acrita* have been reported from the state of Bihar (Sinha *et al.*, 1977; Lal and Das, 1957, 1959; Nath *et al.*, 1976). Haider *et al.* (1986) identified races 1 and 2 of *M. incognita* from the state. *M. incognita* race 1 was found to be distributed in and around Chandigarh (Sharma and Gill, 1992). Swarup (1962) reported the prevalence of *M. incognita, M. incognita acrita* and *M. javanica* on vegetables in Delhi. Sethi *et al.* (1964) also reported the occurrence of *M. javanica* on *Impatiens balsamina* around Delhi. *M. thamesi* was recorded for the first time from India on *Eragrostis pilosa* (Sethi *et al.* 1964). Chitwood and Toung (1960) reported *M. africana* from Delhi. Recently *M. triticoryzae* was reported infecting wheat and rice in Delhi. Race 1 of *M. incognita* was also recorded (Sharma and Gill 1992). *M. incognita* was found to be commonly distributed in Anand area of Gujarat (Shah and Patel, 1979; Patel *et al.*, 1982). Bhatti *et al.* (1974) and Bhatti and Dahiya (1977) reported occurrence of *M. javanica* and *M. incognita* in Haryana. Bajaj *et al.* (1986) identified all the four races of *M. incognita* from the state. Raja and Gill (1982) identified existence of race 1 and race 2 in five *M. incognita* populations obtained form different localities of the state. Occurrence of *M. incognita* races 2 and 4 and *M. javanica* was reported in Solan area of Himachal Pradesh (Bhardwaj *et al.* 1972; Sharma and Gill, 1992). *M. hapla* was reported from the state by Gill (1975).

Krishnappa (1982) and Krishnappa and Setty (1983) found the existence of *M. incognita* in Karnataka. They also detected races 1, 2 and 3 of *M. incognita* in the state. Singh and Krishnaprasad (1986) reported *M. incognita* on potato from the state. Nurseries of strawberries were found to be infected with *Meloidogyne* spp. in Shalimar campus of the Agricultural University in the state of Jammu and Kashmir. (Waliullah and Kaul, 1986). Occurrence of *Meloidogyne* spp. on turmeric was reported from Kerala by Ayyar (1926). It was the first report of occurrence of root-knot nematode in India. *M. incognita* race 1 and *M. javanica* were found major root-knot nematode species distributed in the state of Kerala on many crops (Nadakal and Thomas, 1964; Nair *et al.*, 1969; Raveendran and Nadakal, 1975; Ramana and Mohandas, 1987; Sharma and Gill 1992). Krishnappa (1982) detected *M. incognita* race 1 on groundnut in Madhya Pradesh. Shukla *et al.* (1981) recorded *M. incognita* on ornamental plants at Nagpur in Maharashtra state. *M. graminicola* on rice was reported from Orissa (Rao *et al.*, 1971). Routray and Das (1982) found the existence of races 1 and 2 of *M. incognita* in and around Bhubneswar, Orissa. Kaul and Chhabra (1989) found the existence of *M. incognita, M. javanica, M. arenaria* and *M. graminicola* in Punjab. Ray and Das (1985) reported *M. incognita* on medicinal plants from the state, while Nayak *et al.* (1986) recorded the occurrence of *M. graminis* on wheat. In Rajasthan state, *M. incognita* and *M. javanica* were found associated with different kinds of plants (Mathur *et al.*, 1969; Handa *et al.*, 1971; Soni and Nama, 1982; Trivedi *et al.*, 1986). Siddiqui *et al.* (1986) found *Meloidogyne* spp. quite common in and around Udaipur. Parihar and Yadav (1986) found *M. incognita* in Jaipur, Jodhpur, Sriganganagar and Udaipur of Rajasthan state. Races 1 and 3 of *M. incognita* are common in Rajasthan (Sharma and Gill 1992). *M. incognita* races 1 and 2, *M. javanica* and *M. arenaria* were found to be widely prevalent in Tamil Nadu state (Krishnamurthy and Elias, 1967, 1968; Swamy and Govindo, 1966; Jayaraman *et al.*, 1975; Krishnappa, 1982; Sivagami and Rajendran, 1987). *M. hapla* and *M. brevicauda* were also reported from the state (Seshadri and Kumaraswami, 1963). Singh and Gill (1989) reported *M. incognita* and *M. graminicola* from Tripura state (Table 2).

In the state of Uttar Pradesh, 6 species of *Meloidogyne* viz. *M. incognita, M. javanica, M. arenaria, M. hapla, M. lucknowica* and *M. graminicola* have been reported on several host plants (Verma and Singh, 1983; Sitaramaiah and Vishwakarma, 1978; Mathur and Varaprasad, 1978; Khan *et al.*, 1984, 1987, 1994; Khan and Khan, 1985; 1989a, 1990a, 1991a; Haider and Khan, 1986; Prakash, 1983; Verma 1987; Siddiqui *et al.*, 1986). Singh (1969) described *M. lucknowica* on *Luffa cylindrica* from the state. *M. lucknowica* has now been synonymized with *M. javanica* (Eisenback and Triantaphyllou, 1991). The root-knot nematodes, *M. incognita, M. javanica, M. arenaria, M. hapla, M. acrita* and *M. graminicola* have been reported from West Bengal on a number of host plants (Dutt and Panda, 1968; Dutt and Saha, 1973; Samad, 1960; Sen and Dasgupta, 1975, 1977; Pal and Jayaprakash, 1983; Singh and Khera, 1984). *M. acrita* and *M. thamesi* have been now synonymized with *M. incognita* and *M. arenaria* (Eisenback and Triantaphyllou, 1991). The details of occurrence of the species and races of root-knot nematodes are summarized in Table 2.

Table 2. Species of root-knot nematodes (*Meloidogyne* species) recorded in different states of India

State	Species of *Meloidogyne*	Races of *M. incognita*	Races of *M. arenaria*	Reference
Andaman Islands	*Meloidogyne* incognita *M. javanica*			Salam and Khan (1988) Singh *et al.* (1979),
Andhra Pradesh	*M. incognita* *M. exigua* *M. javanica*	1		Krishnappa (1980), Srinivasan and D'Souza (1965)
Arunachal Pradesh	*M. incognita*			Mishra and Jayaprakash (1980)
Assam	*M. incognita* *M. javanica* *M. graminicola*	1, 2		Roy (1973), Bora and Phukan (1986, Sharma *et al.* (1989), Sharma and Gill (1992).
Bihar	*M. incognita* *M. javanica* *M. arenaria* *M. acrita*	1, 2		Nirula and Kumar (1964, 1966), Sinha *et al.* (1977) Lal and Das (1957, 1959) Haider *et al.* (1986)
Chandigarh	*M. incognita*	1		Sharma and Gill (1992).
Delhi	*M. incognita* *M. javanica* *M. arenaria* *M. thamesi*** *M. incognita acrita** *M. africana* *M. triticoryzae*	1		Swarup (1962), Sethi *et al.* (1964) Sharma and Gill (1992) Chitwood and Toung (1960), Gaur *et al.* (1993)
Gujarat	*M. incognita* *M. javanica* *M. arenaria*			Shah and Patel (1979), Patel *et al.* (1982).

Contd......

Haryana	*M. incognita* *M. javanica*	1,2,3,4	Bhatti *et al.* (1974), Bhatti and Dahiya (1977).
Himachal Pradesh	*M. incognita* *M. javanica* *M. hapla* *M. arenaria*	2,4	Bharadwaj *et al.* (1972), Chandel and Kashyap (1986), Nirula and Kumar (1964, 1966), Kaur and Sharma (1986).
Jammu and Kashmir	*Meloidogyne* spp. *M. hapla*		Waliullah and Kaul (1986) Anon. (1989).
Karnataka	*M. incognita*	1,2,3	Krishnappa (1982), Krishnappa and Setty (1983), Singh and Krishnaprasad (1986).
Kerala	*M. incognita* *M. javanica*	1	Ayyar (1926), Nadakal and Thamas (1964), Raveendran and Nadakal (1975), Ramana and Mohandas (1987), Nair *et al.* (1969).
Madhya Pradesh	*M. incognita*	1	Krishnappa (1982).
Maharashtra	*M. incognita* *M. javanica* *M. arenaria*	2	Shukla *et al.* (1981), Singh and Gill (1986)
Orissa	*M. incognita* *M. javanica* *M. graminicola* *M. graminis*	1,2	Routray and Das (1982), Ray and Das (1985), Rao *et al.* (1971), Das (1986), Nayak *et al.* (1986), Singh and Gill (1989)
Punjab	*M. incognita* *M. javanica* *M. arenaria* *M. graminicola*		Kaul and Chhabra (1989).

Contd.....

Rajasthan	*M. incognita* *M. javanica*	1,3		Mathur *et al.* (1969), Handa *et al.* (1971), Soni and Nama (1982), Trivedi *et al.* (1986), Siddiqui *et al.* (1986), Parihar and Yadav (1986)
Tamil Nadu	*M. incognita* *M. javanica* *M. arenaria* *M. hapla* *M. brevicauda*	1,2		Swamy and Govindu (1966), Jayaraman *et al.* (1975), Krishnamurthy and Elias (1962), Krishnappa (1982), Sivagami and Rajendran (1987), Seshadri and Kumaraswami (1963).
Tripura	*M. incognita* *M. graminicola*			Singh and Gill (1989)
Uttar Pradesh	*M. incognita* *M. javanica* *M. arenaria* *M. lucknowica**** *M. graminicola*	1,2,3,4	2	Verma and Singh (1983), Sitaramaiah and Vishwakarma (1978), Mathur and Varaprasad (1978), Khan *et al.* (1984, 1987, 1994), Khan and Khan (1985, 1989, 1990, 1991), Siddiqui *et al.* (1986), Haider and Khan (1986), Prakash (1983), Singh (1969).
West Bengal	*M. incognita* *M. javanica* *M. arenaria* *M. graminicola* *M. hapla* *M. acrita** *M. thamesi***			Sen and Dasgupta (1975, 1977), Pal and Jaya prakash (1983) Singh and Khera (1984), Dutt and Panda (1986), Dutt and Saha (1973), Samad (1960).

* *M. acrita* synonymized with *M. incognita*.

** *M. thamesi* synonymized with *M. arenaria*.

*** *M. lucknowica* synonymized with *M. javanica*.

(Eisenback and Triantaphyllou, 1991).

Recent studies of Khan (1988), Haider (1989), Khan (1990) and Khan and Khan (1990a, 1991a, 1992) in 34 districts of 68* in the state of Uttar Pradesh showed that *M. incognita* and *M. javanica* were most frequent species of root-knot nematodes followed by *M. arenaria*. *M. hapla* was restricted to cooler areas in the hilly districts. A high percentage of fields grown with vegetables were infested with root-knot nematodes. The species were either found in single or mixed populations. Mixed populations of *M. incognita* with *M. javanica*, *M. incognita* with *M. arenaria*, *M. incognita* with *M. hapla*, *M. javanica* with *M. arenaria*, *M. javanica* with *M. hapla*, *M. arenaria* with *M. hapla* or *M. incognita* with *M. javanica* and *M. arenaria* were encountered. They also recorded the occurrence of four races in *M. incognita* and race 2 in *M. arenaria* populations of the state. Variations in pathogenicity of *M. javanica* on pepper (*Capsicum annuum* L.) were found both in field and pot conditions. However, host races in *M. javanica* populations were not designated.

M. javanica with its extensive host range and wide spread occurrence, is not considered as parasite of pepper even though there are several reports on the contrary. During the survey of root-knot nematodes in Iraq, Stephan (1988) found that pepper crop fields were highly infested with *M. javanica*. He advocated that there might be races in *M. javanica*. Of the 27 cultivars of pepper screened by Jain *et al.* (1983) against *M. javanica*, only ten were found to be susceptible. A similar report was made by Walia and Gupta (1986). Khan (1988) and Khan and Khan (1991b) also found pathogenic variations in *M. javanica* on pepper cultivars.

* The number of districts is now (as in 1997) 83 due to recent creation of new districts in the state.

Host races are well recognized in *M. incognita, M. arenaria* and *M. chitwoodi* in different parts of the world (Sasser, 1980; Taylor and Sasser, 1978; Khan and Khan, 1991a; Santos *et al.* 1985), but occurrence of races in *M. javanica,* one of the most common species, has not been established. Some reports, however, show the possibility of existence of host races in *M. javanica* (Rammah and Hirschmann, 1990).

According to Eisenback and Triantaphyllou (1991), host races in *M. javanica* have not been recognized. Occasionally, however, some populations may reproduce on pepper and more rarely on peanut. These populations have been informally referred to as the 'pepper race' and 'peanut race' of *M. javanica.* There are also report on pathogenic variability among the populations of a race of *Meloidogyne* species. Variability in reproduction and pathogenicity of 12 populations of *Meloidogyne arenaria* race 1 was evaluated on different crops by Noe (1992). He found differences in reproduction among field populations, although the degree of differences was not great.

Recent reports of Khan (1988), Haider (1989) and Khan and Khan (1990a, 1991a) showed that *M. incognita* and *M. javanica* are widely distributed in vegetable fields in the state of Uttar Pradesh. Identification of these two species and their races in a matter of great importance It is likely that populations of *M. incognita* may have more than four known races and there may be distinct races in *M. javanica* populations of the state.

MATERIALS AND METHODS

The different materials used and methods employed to investigate the aspects included and embodied in Section I of the thesis are generalized as follows:

1. Survey and collection

Surveys were conducted in localities of intensive and extensive vegetable cultivations in nine districts of the state of Uttar Pradesh. The selected districts belonged to three regions. 1. Hilly region-Almora, Pauri Garhwal and Dehradun, 2. Central region-Farrukhabad, Hardoi and Sitapur and Eastern region-Basti, Gorakhpur and Deoria of Uttar Pradesh state in India (Figs. 1 & 2). Surveys were conducted to assess the incidence and intensity of root-knot disease on vegetable crops; to establish the identity of species and races of root-knot nematodes especially *M. incognita* and *M. javanica*; and to understand their pattern of distribution in vegetable fields. The following vegetable crops were included.

1. Pepper (*Capsicum annuum* L.)
2. Eggplant (*Solanum melongena* L.)
3. Tomato (*Lycopersicon esculentum* Mill.)
4. Okra (*Abelmoschus esculentus* (L.) *Moen.*)
5. Cucumber (*Cucumis sativus* L.)
6. Cauliflower (*Brassica oleracea* L. var. *botrytis*)
7. Cabbage (*Brassica oleracea* L. var. *capitata*).

Surveys were conducted from March to May for eggplant, pepper, okra, cucumber and from September to November for tomato, cauliflower and cabbage during 1992 to 1995. Five to ten root samples of the above mentioned vegetable crops were collected at random from each of the available cultivation units in the locality under survey. Samples contained in

Fig. 1. Position of Uttar Pradesh in India.

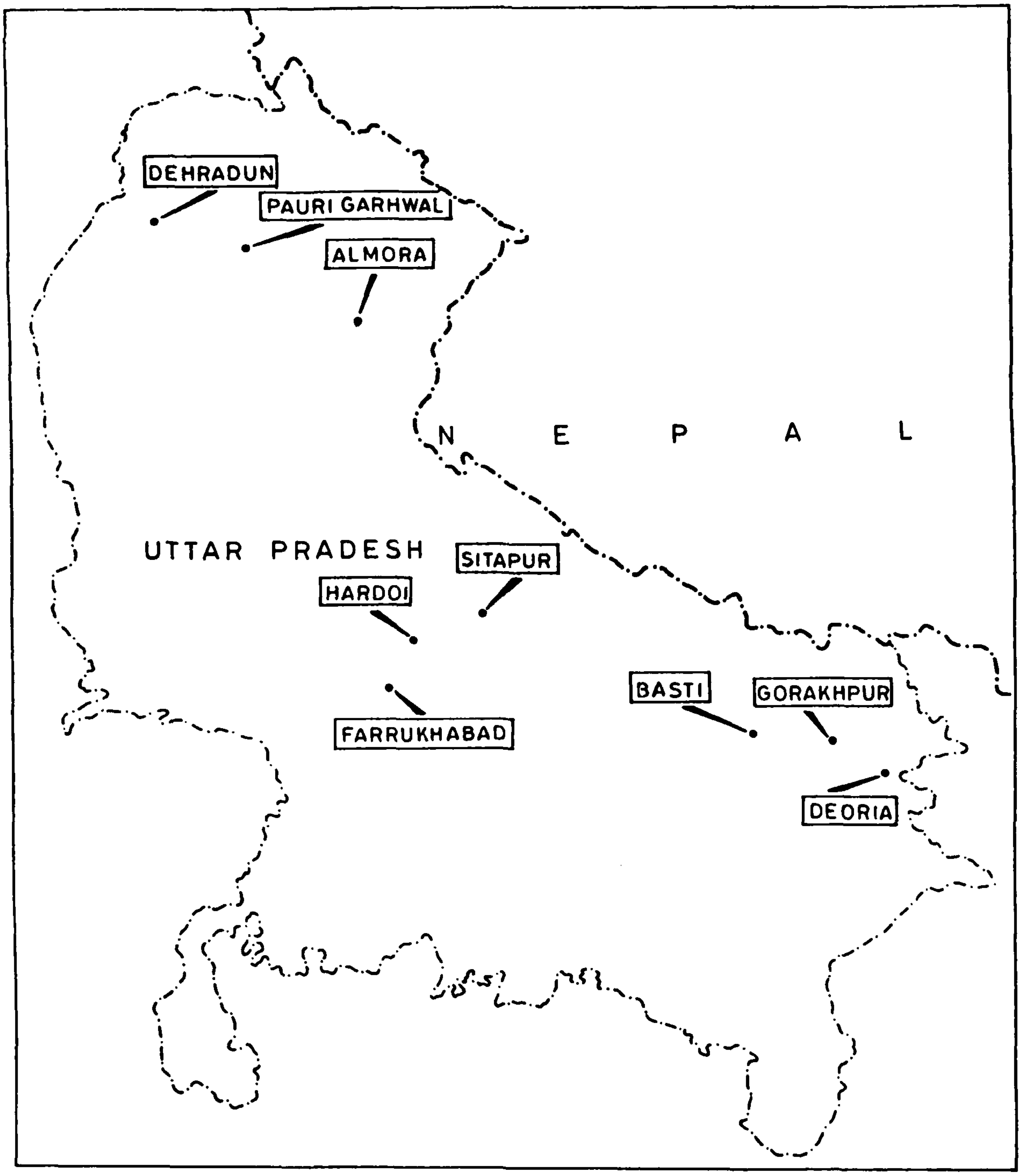

Fig. 2. Districts of Uttar Pradesh included in the survey.

polythene bags were properly labelled and slightly moistened when necessary and brought to laboratory for further examination. Root samples were thoroughly washed under tap water and examined for the presence of galls and egg masses. Number of galls per root system was counted. Roots were immersed in an aqueous solution of phloxin B (0.15g/lit. tap water) for 15 minutes to stain the egg masses. Egg masses per root system were then also counted.

To assess the intensity of the disease, gall index (GI) and egg mass index (EMI) ratings were done according to the following scale. 0 = 0, 1 = 1-2, 2 3-10, 3 = 11-30, 4 = 31-100 and 5 = greater than 100 galls or egg masses per root system (Taylor and Sasser, 1978). Based on gall index (GI) and egg mass index (EMI) ranges, disease intensity grades were made as follows: 0 = disease free; 1 = very mild; 2 = mild; 3 = moderate; 4 = severe; 5 = very severe (Haider, 1989).

To assess the incidence of root-knot disease in different localities of the district in the area under survey on included vegetables, frequency of occurrence of the disease was calculated in two ways:

(a) On the basis of infestation of cultivation units in the locality.

(b) On the basis of infected root samples collected from a locality (Khan and Khan, 1990a).

The frequency of occurrence of the disease in a locality was calculated by the following formula:

$$\text{Frequency (\%)} = \frac{\text{Number of cultivation units from a locality in which infection occurred}}{\text{Total number of cultivation units from the locality surveyed}} \times 100$$

The frequency of occurrence of the disease on the basis of infected root samples was calculated as follows:

$$\text{Frequency (\%)} = \frac{\text{Number of infected root samples collected from the locality}}{\text{Total number of root samples collected from the locality}} \times 100$$

Similarly, frequency of occurrence of the disease on different vegetables in a district was calculated in both ways:

(a) On the basis of infested cultivation units of a vegetable crop in the district.

(b) On the basis of infected root samples of a vegetable crop collected from the district.

Frequency of occurrence (%) of the disease on different vegetable crops on the basis of infested cultivation units was calculated as follows:

$$\text{Frequency (\%)} = \frac{\text{Number of cultivation units of a vegetable crop in the district in which infection occurred}}{\text{Total number of cultivation units of the vegetable surveyed in the district}} \times 100$$

Frequency of occurrence of the disease on different vegetable crops on the basis of infected root samples was calculated as follows:

$$\text{Frequency (\%)} = \frac{\text{Number of infected root samples of a vegetable collected from the district}}{\text{Total number of root samples of the vegetable collected from the district}} \times 100$$

2. Identification of species

Root samples collected from different localities were processed for identification of the species. Fully developed egg masses and the corresponding females were taken out from each sample and same female was identified on the basis of characteristics of perineal pattern in order to determine the species. Perineal patterns of females (10-20) were prepared from each root sample and their characteristics were microscopically examined and noted (Eisenback *et al.*, 1981).

3. Maintenance of species populations

Egg masses were selected from the corresponding females of *M. incognita* and *M. javanica* in the samples. Single egg mass cultures of the species were established separately from various localities of the district surveyed on tomato (cv. Pusa Ruby) or eggplant (Pusa Kranti). Young seedlings (3-4 week-old) of tomato or eggplant transplanted in pots filled with steam sterilized soil were inoculated by adding a single egg mass of the species near the roots. Seedlings in pots inoculated with egg mass were kept in greenhouse with labels to denote the species (identified tentatively), host and locality etc. Subculturing of each population of the species that developed on the seedlings were done approximately every 2-3 months in order to raise sufficient inoculum for further studies. *M. javanica* populations obtained from pepper was maintained separately.

4. Single egg mass cultures

In order to make single egg mass culture of the field populations directly or maintained in glasshouse, a mature egg mass was inoculated in pots around the roots of the susceptible tomato (cv. Pusa Ruby) or eggplant (cv. Pusa Kranti) seedlings for each collection separately. If more than one species were found in same root sample, single egg mass for each of the species was collected and inoculated separately and females producing the same egg masses were dissected out and identified.

Sub-culturing was done after two months by inoculating new seedlings of tomato or eggplant as mentioned above with atleast 15 egg masses, each obtained from the single egg mass culture in order to maintain sufficient inoculum for further studies.

5. Preparation of inoculum

For indentifying the species and races by the North Carolina *differential host test, inoculations of the seedlings of the host differentials* were made either with eggs or second stage juveniles in water suspension. Chlorox method (Hussey and Barker, 1973) was used to obtain eggs for inoculation. Galled roots of tomato/eggplant maintaining single egg mass populations in greenhouse were harvested after 60 days of inoculation. Roots were excised and thoroughly washed with tap water. The roots were cut into small pieces (approximately 1 cm long) and placed in 1000 ml container with 200ml of 0.5% sodium hypochlorite (NaOCl) solution. The tightly capped container was shaken vigorously for three minutes. The gelatinous matrix was partially dissolved by shaking in the NaOCl solution thus freeing eggs from the egg mass. The liquid suspension of eggs was poured through a 200 mesh sieve, nested upon a 500 mesh sieve. Eggs were washed free of residual NaOCl solution under a slow stream of tap water. The concentration of eggs per ml was standardized. The eggs from 10, one ml samples were counted in a counting dish under stereoscopic microscope and the average number was used to represent the number of eggs per ml. Alternatively, second stage juveniles (J2) of the nematodes instead of eggs were also used for inoculation, if necessary. Second stage juveniles (J2) were obtained by incubating egg mass collected from the roots of tomato or eggplant maintaining single egg mass culture of the nematodes, in sterilized distilled water. After 72 hours, number of the hatched juveniles (J2) per ml were standardized by counting ten, one ml samples of the juvenile suspension and the average number was used to represent the number of juveniles per ml.

6. Identification of species and races of root-knot nematodes

Perineal pattern method and North Carolina differential host tests were employed for the identification of species and races of root-knot nematodes. Emphasis was given on the following species of *Meloidogyne*.

1. *Meloidogyne incognita*
2. *Meloidogyne javanica*
3. *Meloidogyne arenaria*
4. *Meloidogyne hapla*

a. Perineal pattern method

Mature females were dissected out from large galls on roots of the susceptible hosts. Perineal patterns (10-20) of each sample were prepared and examined under the microscope and characteristics were noted to identify the species (Eisenback *et al.*, 1981).

b. Differential host test

North Carolina differential host tests (Taylor and Sasser, 1978) were conducted to determine the species and races of *Meloidogyne* collected during the surveys and maintained in the glasshouse. Seedlings of tomato cv. Rutgers, cotton cv. Deltapine 61, tobacco cv. NC 95, pepper cv. California Wonder, peanut cv. Florrunner and watermelon cv. Charleston Grey were grown in 15 cm clay pots filled with sandy loam soil with three replications. Plants were inoculated at the rate of 5,000 freshly hatched second stage juveniles (J2)/pot. Juveniles were pipetted into 4-5 holes made in the soil around each seedling. Pots were placed on benches in the glasshouse at temperature 25±2°C. Sixty days after inoculation, the plants were uprooted and washed thoroughly with tap water and examined for the presence of galls. Roots with very light infection were stained with phloxin B to determine the number of egg masses. Galls and egg masses were counted and rated on Taylor and Sasser's scale as mentioned earlier under the survey. After rating the root system, results were compared with the North Carolina differential host test reaction chart (Table 3) (Taylor and Sasser, 1978). This distinguished the four species of *Meloidogyne* viz. *M. incognita, M. javanica, M. arenaria, M. hapla.* The identification of species done on the basis of differential host test were compared with identification made earlier by perineal pattern method for confirmation of their identity. Differentiation of races was based on the results of differential host test and its comparison with the differential host test reaction chart (Table 3).

7. Races in *Meloidogyne javanica* populations

During host differential test *M. javanica* showed two types of reactions on pepper cv. California Wonder. Therefore, for further differentiation and identification of races in *M. javanica*, all the populations of this nematodes were tested for their pathogenicity on pepper cv. California Wonder already recognised resistant (Taylor and Sasser, 1978) and on cv. Suryamukhi Green reported to be susceptible to this species (Khan and Khan, 1991b). The seeds of the both cultivars were raised separately in 12 cm. clay pots containing 2 kg autoclaved sandy loam soil. Five pots of each cultivar (California Wonder and Suryamukhi Green) were inoculated with 5000 freshly hatched second stage juveniles (J2) of each populations of *M. javanica,* maintaining single egg mass cultures. After inoculation pots were arranged in complete randomized blocks and maintained at 25±2°C at glasshouse benches.

Table 3. North Carolina Differntial Host Reaction Chart

Meloidogyne species and races	Cotton cv. Deltapine 61	Tobacco cv. NC 95	Pepper cv. California Wonder	Watermelon cv. Charleston Grey	Peanut cv. Florrunner	Tomato cv. Rutgers
M. incognita						
Race 1	-[1]	-	+	+	-	+
Race 2	-	+	+	+	-	+
Race 3	+	-	+	+	-	+
Race 4	+	+	+	+	-	+
M. javanica	-	+	- (+)[2]	+	- (+)	+
M. arenaria						
Race 1	-	+	+	+	+	+
Race 2	-	+	+	+	-	+
M. hapla	-	+	+	-	+	+

1 Box indicates key differential host plants.
2 Parentheses indicate that a small proportion of the populations attack that host.

After 60 days plants were removed from pots and washed to discard adhered soil particles. The number of galls and egg masses present on root systems were counted and GI and EMI rated were on Taylor and Sasser's scale as mentioned earlier. After rating results were compared with the following table.

Table 4. Host test reaction chart for the proposed races of *Meloidogyne javanica*.

	Resistant	Susceptible	Race
Cultivar	California Wonder	Suryamukhi Green	
Reaction	-	+	A
	+	+	B

Thus two races of *M. javanica*, Race A and Race B were categorized.

8. Frequency of occurrence of species

After identification of the species present in the samples, frequency of different species of *Meloidogyne* in single populations as well in mixed populations of different species combinations occurring in a locality was calculated as follows:

For single species populations,

$$\text{Frequency (\%)} = \frac{\text{Number of infected root samples with single species populations in a locality}}{\text{Total number of infected root samples collected from the locality}} \times 100$$

For mixed species populations of different species combination,

$$\text{Frequency (\%)} = \frac{\text{Number of infected root samples with mixed species population of a particular species combination in a locality}}{\text{Total number of infected root samples collected from the locality}} \times 100$$

For comparative assessment of dominance of a species in different localities in a district either in single or in mixed population, frequency of different species in single as well as mixed populations of different species combinations among different localities of the district were calculated as follows:

For single species populations,

$$\text{Frequency (\%)} = \frac{\text{Number of the infected root samples with single species in a locality of the district}}{\text{Total number of infected root samples collected from all the localities of district}} \times 100$$

For mixed species populations of different species combinations,

$$\text{Frequency (\%)} = \frac{\text{Number of infected root samples with mixed species population of a particular species combination in a locality of the district}}{\text{Total number of infected root samples collected from all the localities of a district}} \times 100$$

Thenafter, frequency of occurrence of different species of *Meloidogyne* recorded in different localities of the district based on total infected root samples regardless of single or mixed species population was calculated as follows:

$$\text{Frequency (\%)} = \frac{\text{Number of root samples infected with the species}}{\text{Total number of infected root samples}} \times 100$$

Similarly, frequency of occurrence of a recorded species of *Meloidogyne* among different localities of the district irrespective of single or mixed species populations was calculated as follows:

$$\text{Frequency (\%)} = \frac{\text{Number of root samples infected with the species in a locality of the district}}{\text{Total number of infected root samples collected from all the localities of the district}} \times 100$$

9. Frequency of occurrence of races

Frequency of occurrence of different races of *M. incognita* and *M. javanica* and *M. arenaria* identified in different localities of the district based on total infected root samples of the respective species, was calculated as follows:

$$\text{Frequency (\%)} = \frac{\text{Number of root samples infected with the race of the species in a locality}}{\text{Total number of infected root samples with the species in the locality}} \times 100$$

Frequency of occurrence of a identified race of *Meloidogyne incognita, M. javanica* and *M. arenaria* among different localities of the district was calculated as follows:

$$\text{Frequency (\%)} = \frac{\text{Number of root samples with the race of the species in a locality of the district}}{\text{Total number of infected root samples with the race collected from all the localities of the district}} \times 100$$

10. Overall assessment

For overall assessment of the incidence of the root-knot disease in the area under survey on included vegetables, frequency of occurrence (%) of the disease in different district was also calculated accordingly on the basis of infestation of cultivation units in the district as well as on the basis of infected root samples collected from a district (Table 50).

Similarly frequency of occurrence (%) of the disease on different vegetables in the area, was calculated on the basis of infected cultivation units of a vegetable crop in the area. Based on root samples, frequency of occurrence (%) of the disease on different vegetables in whole area was also calculated (Table 51).

Intensity of the disease in different districts and on different vegetables was assessed based on average GI and EMI (Tables 51).

Frequency of occurrence (%) of the species of *Meloidogyne* in single and mixed populations (with different combinations) was also calculated for the each district. Thenafter, frequency of occurrence (%) of the species in each district was calculated on the basis of total infected root samples (Table 52). Frequency of occurrence (%) of a species among districts either in single or mixed populations as well as frequency of occurrence (%) of a species among the districts based in total infected root samples were also calculated (Table 53).

Frequency of occurrence (%) of races of *M. incognita, M. javanica* and *M. arenaria* was calculated for different districts and of a race among the districts of the area to assess their comparative dominance (Table 54).

RESULTS

Meloidogyne javanica populations collected from the localities of the districts in the study area exhibited pathogenic variability on pepper cultivars and two distinct kinds of populations were differentiated. These populations were tentatively designated as race A and race B. In *M. incognita* populations, pathogenic variability also existed. Four known races (races 1-4), based on their pathogenicity on specific cultivars of North Carolina host differentials, were recognised in *M. incognita* populations collected from the stduy area. Race 2 alone comprised *M. arenaria* population.

California Wonder and Suryamukhi Green, known to be resistant and susceptible respectively to *M. javanica*, were inoculated with the maintained populations (295) of *M. javanica* in order to determine their pathogenic variability. Host reactions (-= resistant, +=susceptible) were assigned to the cultivars following the Canto-Saenz scheme as modified by Sasser *et al.* (1984). California Wonder was not infected by most of the populations of *M. javanica* as the reaction of the California Wonder was negative(-). It was, however, infected by one third populations of *M. javanica* included in the test. On the other hand, Suryamukhi Green was infected by all the populations. Reproduction factor (Rf) for all the populations on this cultivar was invariably greater than 2. Therefore, this cultivar showed positive (+) reaction to all the populations and was designated as susceptible. Based on this variable response of the cultivars, the 207 populations which could not infect California Wonder comprised race A and 88 populations which could infect California Wonder comprised race B of *M. javanica*. Therefore, the ratio of the races in the analysed populations was 7:3 (Table 5).

Table 5. **Reaction of cultivars of pepper California Wonder and Suryamukhi Green to the populations of *Meloidogyne javanica* collected from various localities**

Region/District	Locality	Reaction of cultivars: California Wonder	Reaction of cultivars: Suryamukhi Green	Designated Race of *M. javanica*	No. of infected samples: Race A	No. of infected samples: Race B
Hilly region						
Almora	Almora proper	-	+	A	5	
		+	+	B		2
	Ranikhet	-	+	A	6	
		+	+	B		3
	Bageshwar	-	+	A	2	
Pauri Garhwal	Pauri Garhwal	-	+	A	11	
		+	+	B		4
	Kandi	-	+	A	6	
	Churani	-	+	A	1	
		+	+	B		2
Dehradun	Dehradun Proper	-	+	A	7	
				B		3
	Chakrauta	-	+	A	4	
		+	+	B		2
	Rishikesh	-	+	A	5	
		+	+	B		2

Contd.....

Region/District	Locality	Reaction of cultivars		Designated	No. of infected samples	
		California Wonder	Suryamukhi Green	Race of *M. javanica*	Race A	Race B
Central region						
Farrukhabad	Farrukhabad proper	-	+	A	11	
		+	+	B		4
	Kaimganj	-	+	A	4	
		+	+	B		3
	Jalalabad	-	+	A	7	
		+	+	B		3
Hardoi	Hardoi proper	-	+	A	10	
		+	+	B		3
	Shahabad	-	+	A	7	
		+	+	B		5
	Sandila	-	+	A	6	
		+	+	B		3
Sitapur	Sitapur proper	-	+	A	13	
		+	+	B		7
	Sadarpur	-	+	A	17	
		+	+	B		8
	Hargaon	-	+	A	10	
		+	+	B		4

Contd.....

Region/District	Locality	Reaction of cultivars		Designated Race of *M. javanica*	No. of infected samples	
		California Wonder	Suryamukhi Green		Race A	Race B
Eastern region						
Basti	Basti proper	-	+	A	10	
		+	+	B		4
	Khalilabad	-	+	A	7	
		+	+	B		4
	Dumariaganj	-	+	A	7	
		+	+	B		2
Gorakhpur	Gorakhpur proper	-	+	A	11	
		+	+	B		5
	Maharajganj	-	+	A	8	
		+	+	B		3
	Gola Bazar	-	+	A	12	
		+	+	B		4
Deoria	Deoria proper	-	+	A	6	
		+	+	B		3
	Salimpur	-	+	A	5	
		+	+	B		3
	Padrauna	-	+	A	9	
		+	+	B		2
Total					207	88

- = Resistant
+ = Susceptible

ALMORA

Incidence and intensity of the disease

Root samples of vegetables were collected from three localities (Almora proper, Ranikhet and Bageshwar) of the Almora district (Fig. 3). The per cent frequency of the disease in vegetable fields of the localities ranged from 40 to 50. The incidence of the disease was highest in Almora proper followed by Ranikhet and Bageshwar. Average frequency was 45% in the district. On root sample basis, the frequency was also highest in Almora proper and lowest in Bageshwar. Average was about 29% (Table 6).

The highest intensity of disease was observed in Ranikhet. Based GI/EMI, the disease intensity in the localities of the district was mild to very severe.

Incidence of the disease on the vegetable crops in different vegetable fields varied. Highest frequency was observed in cabbage (100%) fields followed by eggplant (60%), pepper (50%), tomato (50%), okra (33%) and cucumber (33%) fields. However, cauliflower fields were found to be free from infestation. On the basis of root samples, highest frequency was found on eggplant (42.55%) and lowest on cabbage (12.50%) (Table 7).

Highest intensity based on GI and EMI was observed (3-5 and 3-5) on tomato roots. On other vegetables, GI/EMI range was 2-5/2-5 (Table 7).

Identity of the species

Four species of root-knot nematodes, *M. incognita, M. javanica, M. arenaria* and *M. hapla* were identified infecting vegetables in Almora district (Fig. 3, Table 8). The species were found either in single or mixed populations.

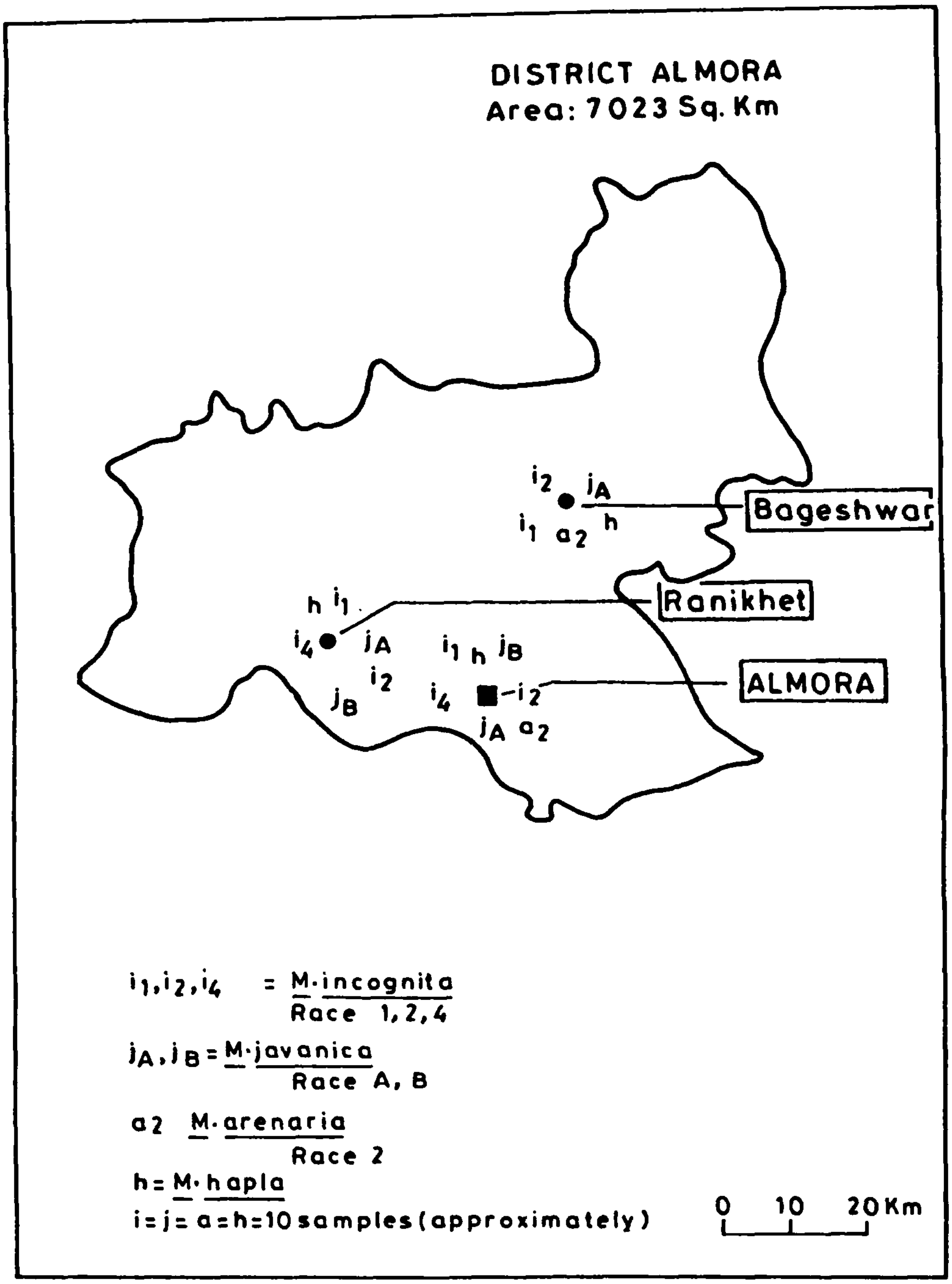

Fig. 3. Distribution of *Meloidogyne* species and their races in Almora district.

Table 6. Incidence and intensity of root-knot nematodes on vegetable crops in different localities of Almora district

Locality	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Almora proper	8	4	50.00	72	25	34.72	2-5/2-5
Ranikhet	9	4	44.44	64	18	28.12	3-5/3-5
Bageshwar	5	2	40.00	40	08	20.00	2-5/2-5
Total	22	10	45.45	176	51	28.97	2-5/2-5

* GI = Gall index; EMI = Egg mass index.

Table 7. Incidence and intensity of root-knot nematodes on different vegetable crops in Almora district

Crop	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Pepper	4	2	50.00	28	08	28.57	2-5/2-5
Eggplant	5	3	60.00	47	20	42.55	2-5/1-5
Tomato	4	2	50.00	36	13	36.11	3-5/3-5
Okra	3	1	33.33	15	05	33.33	2-5/2-5
Cucumber	3	1	33.33	24	04	16.66	2-5/2-5
Cauliflower	2	-	-	18	-	-	-
Cabbage	1	1	100.00	08	01	12.50	2-5/2-5

* GI = Gall index; EMI = Egg mass index.

Frequency of species in single and mixed populations

In single populations, *M. incognita* and *M. hapla* were present in Almora proper; *M. javanica* and *M. hapla* in Ranikhet; and *M. incognita* and *M. arenaria* in Bageshwar. The frequency of *M. incognita* was greater than other species in Almora proper and Bageshwar; and of *M. javanica* in Ranikhet. Among the localities, *M. incognita* and *M. hapla* were more frequent in Almora proper and Ranikhet respectively than other localities. *M. javanica* and *M. arenaria* were encountered only from Rainkhet and Bageshwar, respectively. Therefore, their frequencies were 100% in these localities (Table 8).. *M. incognita* with *M. arenaria*; *M. incognita* with *M. hapla; M. arenaria* with *M. hapla; M. incognita, M. javanica* and *M. arenaria* were found together in mixed populations in different localities. *M. incognita* with *M. hapla* was present in all the localities while other combinations were present only in some localities. In Almora proper, *M. incognita* + *M. javanica* + *M. arenaria* was greater than other combinations. In Ranikhet and Bageshwar localities, *M. incognita* + *M. hapla* combination was more frequent than other combinations. Among the localities, *M. incognita* + *M. javanica* and *M. incognita* + *M. hapla* combinations were more frequent in Rainkhet than other two localities. Since combinations of *M. incognita* + *M. arenarai*, *M. arenarai* + *M. hapla* and *M. incognita* + *M. javanica* + *M. arenaria* were recorded only from Almora proper, their frequencies were 100% (Table 8).

Frequency of the species in total infected samples

In Almora proper frequency of *M. incognita* (88%) was highest in total infected samples followed by *M. arenaria* (44%). *M. javanica* and *M. hapla* were equally frequent. In Ranikhet, frequency of *M. javanica* and *M. hapla* was equal (50%) while of *M. incognita* was slightly less (44.44%).

Table 8. Frequency of occurrence of species (%) of the root-knot nematodes in single and mixed populations on vegetable crops in different localities of Almora district

Locality	Frequency of species									
	Single population				Mixed population					
	Mi	Mj	Ma	Mh	Mi+Mj	Mi+Ma	Mi+Mh	Mj+Ma	Ma+Mh	Mi+Mj+Ma
Almora proper	32.00*	-	-	8.00	-	12.00	16.00	-	4.00	28.00
	(80.00)**			(33.33)		(100.00)	(33.33)		(100.00)	(100.00)
Ranikhet	-	33.33	-	22.22	16.66	-	27.77	-	-	-
		(100.00)		(66.66)	(60.00)		(41.66)			
Bageshwar	25.00	-	12.50	-	25.00	-	37.50	-	-	-
	(20.00)		(100.00)		(40.00)		(25.00)			

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria;* Mh = *M. hapla.*

Frequency of *M. incognita* (87.50%) was highest in Bageshwar followed by *M. hapla* (37.50%), *M. javanica* (25%) and *M. arenaria* (12.50%) (Table 9).

In total infected samples among the localities, highest frequency was observed for *M. arenaria* (91.66%) followed by *M. incognita* (59.45%) in Almora proper than other species in different localities. In Bageshwar, however, *M. arenaria* showed lowest frequency (8.33%) (Table 9).

Identity and frequency of the races

Races 1, 2 and 3 of *M. incognita;* races A and B of *M. javanica* and race 2 of *M. arenaria* were recorded from the district. Race 3 of *M. incognita* and race 1 of *M. arenaria* were not found in the district (Fig. 3). Among the populations of *M. incognita,* race 1 showed highest frequency (71.43%) in Bageshwar and race 4 lowest (12.50%) in Ranikhet as compared to other races. Among the localities, frequency of race 4 (83.33%) was highest in Almora proper and of race 2 lowest in Bageshwar (Table 10).

In *M. javanica* two races were recognized. These two races are designated as race A and race B. In Almora proper and Ranikhet, frequencies of race A were greater than race B. In Bageshwar, frequency of race A was 100% as this race alone comprised *M. javanica* populations of the locality.

Among the localities, frequency of race A (46.15%) was highest in Ranikhet and lowest in Bageshwar. Frequency of race B (60%) was also highest in Ranikhet.

M. arenaria population recorded from Almora proper and Bageshwar contained only race 2. Therefore, frequency of this race was 100%.

Table 9. Frequency of occurrence of the species (%) of root-knot nematodes in different localities of Almora district based on total infected root samples of vegetables

Locality	Total infected root samples	No. of root samples infected (Single +Mixed population)				Frequency of species in total infected samples			
		Mi	Mj	Ma	Mh	Mi	Mj	Ma	Mh
Almora proper	25	22	07	11	07	88.00*	28.00	44.00	28.00
						(59.45)**	(38.88)	(91.67)	(36.84)
Ranikhet	18	08	09	-	09	44.44	50.00	-	50.00
						(21.62)	(50.00)		(47.36)
Bageshwar	08	07	02	01	03	87.50	25.00	12.50	37.50
						(18.91)	(11.11)	(8.33)	(15.78)

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria*; Mh = *M. hapla.*

Table 10. Frequency of occurrence of races of *Meloidogyne incognita* (Mi), *Meloidogyne javanica* (Mj) and *Meloidogyne arenaria* (Ma) in different localities of Almora district

Locality	Species/ Races	Frequency (%) of the races of *Mi*				Frequency (%) of the races of *Mj*		Frequency (%) of the races of *Ma*	
		R_1	R_2	R_3	R_4	A	B	R_1	R_2
Almora proper	Mi_{R1}, Mi_{R2}, Mi_{R4},	45.45*	31.81	-	22.72	71.42	28.57	-	100.00
	Mj_A, Mj_B, Ma_{R2},	(52.63)**	(58.33)		(83.33)	(38.46)	(40.00)		(91.67)
Ranikhet	Mi_{R1},Mi_{R2},Mi_{R4},	50.00	37.50	-	12.50	66.67	33.33	-	Nil
	Mj_A, Mj_B	(21.05)	(25.00)		(16.67)	(46.15)	(60.00)		
Bageshwar	Mi_{R1}, Mi_{R2},	71.43	28.57	-	-	100.00	-	-	100.00
	Mj_A, Ma_{R2}	(26.31)	(16.66)			(15.38)			(8.33)

* Values in rows represent frequency (%) of the races in the same locality.

** Values in parentheses in the columns of the races represent frequency (%) of the races of in different localities.

Mi = *M. incognita*; Mj = *M. javanica*; Ma = *M. arenaria*.

R_1 = race 1; R_2 = race 2; R_3 = race 3 and R_4 = race 4 of *M. incognita* or *M. arenaria*.

A = race A and B = race B of *M. javanica*.

When frequencies among the localities were compared highest (91.67%) frequency was found in Almora proper and lowest in Bageshwar (8.33%) (Table 10).

PAURI GARHWAL

Incidence and intensity of the disease

Three localities of Pauri Garhwal district, Pauri Garhwal proper, Kandi and Churani were surveyed (Fig. 4). Incidence of the disease was highest in Churani followed by Pauri Garhwal and Kandi. Average incidence of disease in vegetable fields was 44% in the district (Table 11). On root samples basis, incidence was highest in Pauri Garhwal followed by Kandi. Lowest incidence was recorded in Churani. In total, 37% root samples were infected (Table 11).

Intensity of disease was moderate to very severe (3-5/3-5) in Pauri Garhwal and mild to very severe (2-5/2-5) in Kandi and Churani. Incidence of the disease was highest in eggplant fields followed by cucumber, cabbage and tomato fields. Lowest incidence was observed in okra fields. Cauliflower fields surveyed were free from infection (Table 12). Root samples of eggplant (46.52%) showed highest percentage of infection followed by tomato (38.23%). Lowest frequency of the disease was on cabbage roots (16.66%) (Table 12).

Highest disease intensity was observed on eggplant roots. GI/EMI ranges were 4-5/4-5. On other vegetables, intensity was mild to very severe (2-5/2-5) (Table 12).

Identity of the species

All the four major species of root-knot nematodes, *M. incognita, M. javanica, M. arenaria, M. hapla* were recorded from the district (Fig. 4, Table 13). Species were found either single or in mixed populations.

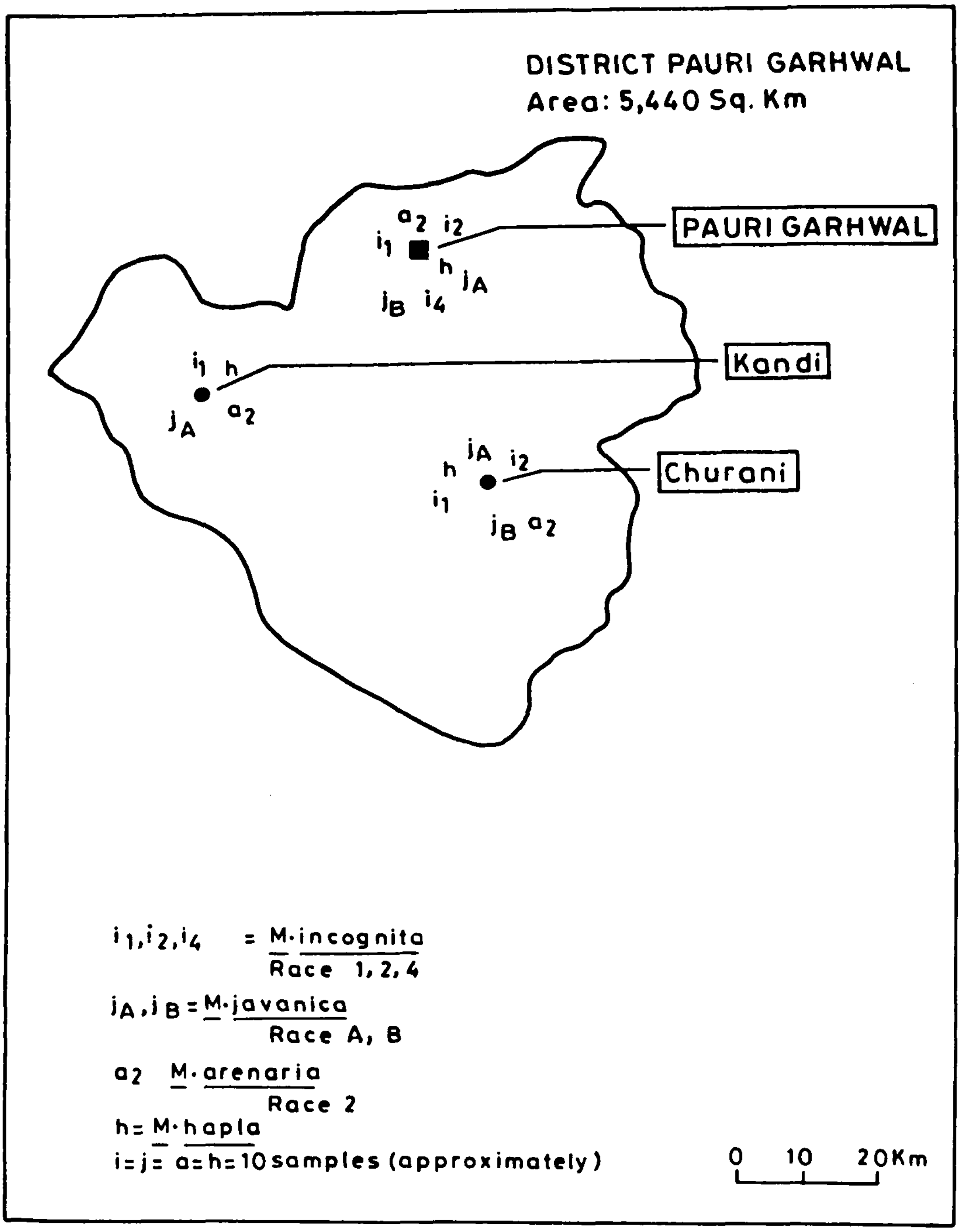

Fig. 4. Distribution of *Meloidogyne* species and their races in Pauri Garhwal district.

Table 11. Incidence and intensity of root-knot nematodes on vegetable crops in different localities of Pauri Garhwal district

Locality	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Pauri Garhwal proper	7	3	42.85	58	25	43.10	3-5/3-5
Kandi	8	3	37.50	46	18	39.13	2-5/2-5
Churani	10	5	50.00	50	14	28.00	2-5/2-5
Total	25	11	44.00	154	57	37.01	2-5/2-5

* GI = Gall index; EMI = Egg mass index.

Table 12. Incidence and intensity of root-knot nematodes on different vegetable crops in Pauri Garhwal district

Crop	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Pepper	3	1	33.33	24	08	33.33	2-5/2-5
Eggplant	8	5	62.50	46	26	46.52	4-5/4-5
Tomato	5	2	40.00	34	13	38.23	3-5/3-5
Okra	4	1	25.00	20	06	30.00	3-5/2-5
Cucumber	2	1	50.00	08	02	25.00	2-5/2-5
Cauliflower	1	-	-	10	-	-	-
Cabbage	2	1	50.00	12	02	16.66	2-5/2-5

* GI = Gall index; EMI = Egg mass index.

Frequency of species in single and mixed populations

In Pauri Garhwal proper, *M. javanica* was the only species present in single species populations. *M. incognita, M. javanica* and *M. arenaria* were present in single speices populations in Kandi and *M. incognita* and *M. hapla* in Churani.

In mixed populations, *M. incognita* was present with other species in general, while combinations of *M. javanica* and *M. arenaria* and *M. arenaria* and *M. hapla* were not very common. In Pauri Garhwal, irrespective of single or mixed populations, highest frequency was observed for Mi + Mj combination (28%) and lowest (8%) for Mi+Ma combination. In Kandi and Churani, frequencies of *M. arenaria* (22.22%) and *M. incognita* (35.71%) were greater than other single or mixed populations, respectively (Table 13). Among the localities, frequencies of *M. arenaria* and *M. hapla* in single species populations were 100% in Kandi and Churani, respectively and lowest frequency was for Mj+Ma (25%) in Churani.

Frequency of the species in total infected samples

In total infected samples, *M. incognita* was more frequent than other species in all the localities except in Pauri Garhwal where *M. javanica* dominated (60%) (Table 14). *M. hapla* was less frequent as compared to other species in all the localities. All the species showed highest frequency in Pauri Garhwal when frequency was compared among the localities (Table 14).

Identity and frequency of the races

Three races of *M. incognita* (races 1, 2, and 4); two races of *M. javanica* (races A and B) and race 2 of *M. arenaria* were identified in the samples from the district (Fig. 4, Table 15). In Pauri Garhwal proper

Table 13. Frequency of occurrence of species (%) of the root-knot nematodes in single and mixed populations on vegetable crops in different localities of Pauri Garhwal district

Locality	Frequency of species									
	Single population				Mixed population					
	Mi	Mj	Ma	Mh	Mi+Mj	Mi+Ma	Mi+Mh	Mj+Ma	Ma+Mh	Mi+Mj+Ma
Pauri Garhwal	-	20.00*	-	-	28.00	8.00	16.00	12.00	16.00	-
Proper		(71.42)**			(70.00)	(40.00)	(57.14)	(75.00)	(66.66)	
Kandi	16.66	11.11	22.22	-	16.66	-	16.66	-	11.11	5.55
	(37.50)	(28.57)	(100.00)		(30.00)		(42.85)		(33.33)	(33.33)
Churani	35.71	-	-	21.42	-	21.42	-	7.14	-	14.28
	(62.50)			(100.00)		(60.00)		(25.00)		(66.66)

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria;* Mh = *M. hapla.*

Table 14. Frequency of occurrence of the species (%) of root-knot nematodes in different localities of Pauri Garhwal district based on total infected root samples of vegetables

Locality	Total infected root samples	No. of samples infected (Single +Mixed Population)				Frequency of species in total infected samples			
		Mi	Mj	Ma	Mh	Mi	Mj	Ma	Mh
Pauri Garhwal proper	25	13	15	09	08	52.00* (39.39)**	60.00 (62.50)	36.00 (40.91)	32.00 (50.00)
Kandi	18	10	06	07	05	55.55 (30.30)	33.33 (25.00)	38.88 (31.82)	27.77 (31.25)
Churani	14	10	03	06	03	71.42 (30.30)	21.42 (12.50)	42.85 (27.27)	21.42 (18.75)

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria*; Mh = *M. hapla.*

Table 15. Frequency of occurrence of races of *Meloidogyne incognita* (Mi), *Meloidogyne javanica* (Mj) and *Meloidogyne arenaria* (Ma) in different localities of Pauri Garhwal district

Locality	Species/ Races	Frequency (%) of the races of *Mi*				Frequency (%) of the races of *Mj*		Frequency (%) of the races of *Ma*	
		R_1	R_2	R_3	R_4	A	B	R_1	R_2
Pauri Garhwal proper	Mi_{R1}, Mi_{R2}, Mi_{R4}, Mj_A, Mj_B, Ma_{R2},	46.15* (31.58)**	30.77 (33.36)	-	23.08 (100.00)	73.33 (61.11)	26.67 (66.67)	-	100.00 (40.91)
Kandi	Mi_{R1}, Mj_A, Ma_{R2},	100.00 (52.63)	-	-	-	100.00 (33.33)	-	-	100.00 (31.82)
Churani	Mi_{R1}, Mi_{R2}, Mj_A, Mj_B, Ma_{R2},	30.00 (15.79)	70.00 (63.64)	-	-	33.33 (5.56)	66.67 (33.33)	-	100.00 (27.27)

* Values in rows represent frequency (%) of the races in the same locality.

** Values in parentheses in the columns of the races represent frequency (%) of the races of in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

R_1 = race 1; R_2 = race 2; R_3 = race 3 and R_4 = race 4 of *M. incognita* or *M. arenaria.*

A = race A and B = race B of *M. javanica.*

and Kandi, race 1 of *M. incognita;* race A of *M. javanica* were more frequent than other races of the respective species. In Churani, race 2 of *M. incognita* and race B of *M. javanica* were greater in frequency than other races. Frequency of *M. arenaria*, race 2 was 100% in all the localities. Race 4 of *M. incognita* was present only in Pauri Garhawal proper.

Among the localities, frequency of race 1 (100%) of *M. incognita* in Kandi and Pauri Garhwal and race 2 in Churani were highest. Frequency of race 4 was 100% in Pauri Garhwal proper because only this race was present in this locality. Frequency of race A (61.11%) and B (66.67%) of *M. javanica* and race 2 of *M. arenaria* (40.91%) were highest in Pauri Garhwal (Table 15).

DEHRADUN

Incidence and intensity of the disease

Root samples of vegetables were collected from three localities of Dehradun district, namely Dehradun proper, Rishikesh and Doiwala (Fig. 5). Incidence of the root-knot disease in the vegetable fields was 50% in Dehradun proper and Rishikesh and 43% in Doiwala. Cauliflower and cabbage fields were found free from infestation (Table 16). Incidence of the disease on root sample basis was highest (33.75%) in Dehradun proper followed by Rishikesh (30%) and Doiwala (18.75%).

Intensity of the disease was moderate to very severe (3-5/3-5) in Dehradun proper and Rishikesh, and mild to severe (2-5/2-5) in Doiwala (Table 16).

Among the vegetables, highest incidence of the disease was observed in cucumber fields followed by eggplant, tomato and okra and

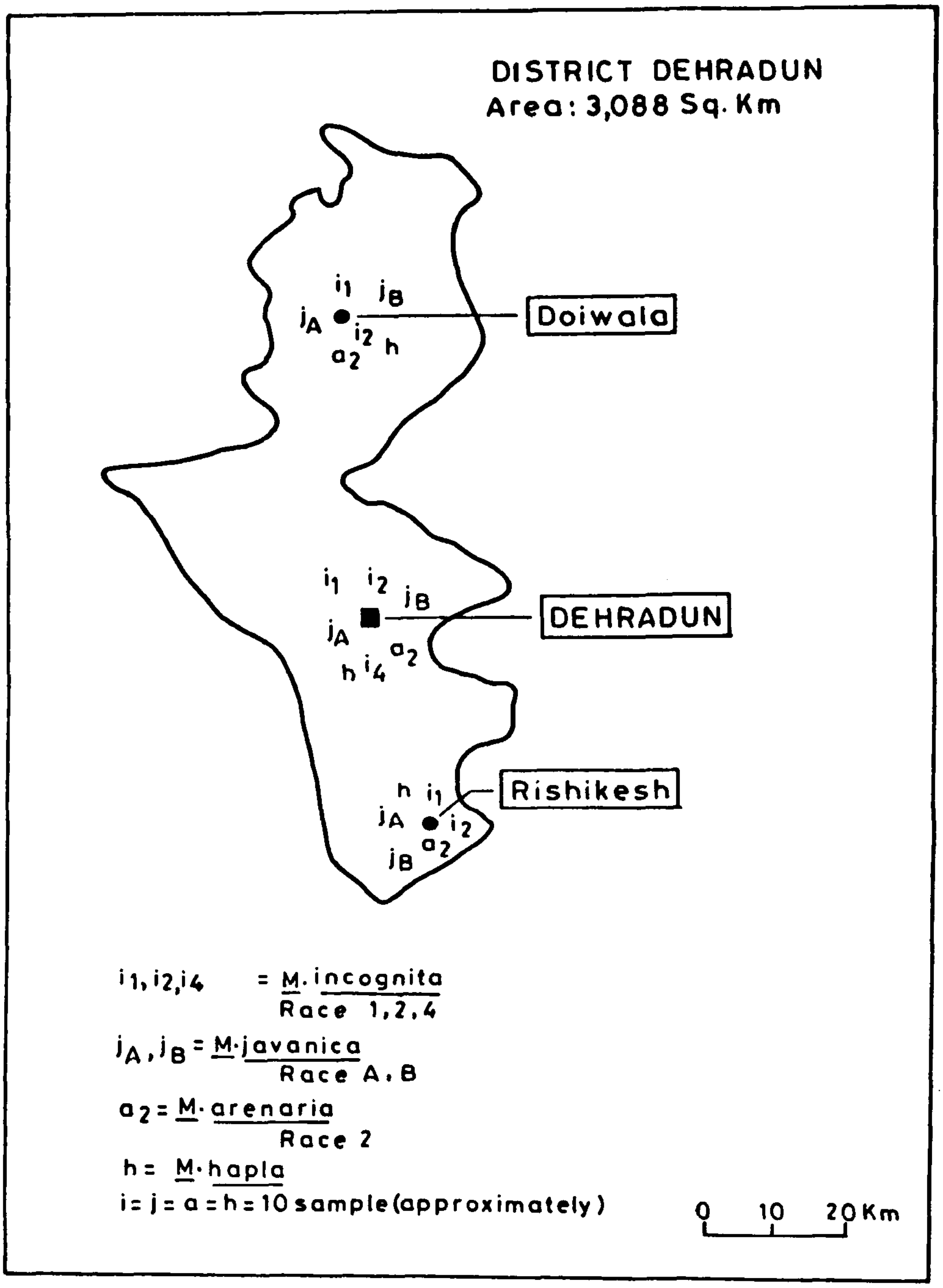

Fig. 5. Distribution of *Meloidogyne* species and their races in Dehradun district.

Table 16. Incidence and intensity of root-knot nematodes on vegetable crops in different localities of Dehradun district

Locality	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Dehradun proper	10	5	50.00	80	27	33.75	3-5/3-5
Rishikesh	6	3	50.00	60	18	30.00	3-5/2-5
Doiwala	7	3	42.85	64	12	18.75	2-5/2-5
Total	23	11	47.82	204	57	27.94	2-5/2-5

* GI = Gall index; EMI = Egg mass index.

lowest (33.33%) in pepper fields. On root sample basis, incidence of the disease was highest on eggplant (41.07%) and lowest on cucumber (16.66%). The incidence on tomato (28.33%) and pepper (27.02%) was almost equal (Table 17).

The disease intensity was highest on eggplant followed by tomato in the district. The intensity was moderate to very severe (3-5/3-5) on these two vegetable crops. Mild to severe intensity (2-5/2-5) was, however, observed on pepper, okra and cucumber.

Identity of the species

Four species of root-knot nematodes, viz., *M. incognita, M. javanica, M. arenaria* and *M. hapla* were found in all three localities (Fig. 5). Single populations of *M. incognita, M. javanica* and *M. hapla* and mixed populations of *M. incognita* with *M. javanica, M. incognita* with *M hapla, M. arenaria* with *M. hapla, M. incognita* and *M. javanica* with *M. arenaria* were recorded from one or the other localities. *M. arenaria* was not found in any locality in single population (Table 18).

Frequency of the species in single and mixed populations

In single populations, frequency of *M. incognita* was greater than other species in Dehradun proper and Rishikesh. Frequency of *M. javanica* (5.55%) was lowest in Rishikesh.

Among the localities, *M. incognita* (58.33%), *M. javanica* (62.50%) and *M. hapla* (57.14) were more frequent in Dehradun proper than in Rishikesh and Doiwala (Table 18).

The frequency of mixed populations of *M. incognita* with *M. hapla* (33.33%) was greater than other combinations in all the localities. Lowest

Table 17. Incidence and intensity of root-knot nematodes on different vegetable crops in Dehradun district

Crop	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Pepper	6	2	33.33	60	17	28.33	2-5//2-5
Eggplant	7	4	57.14	56	23	41.07	3-5/3-5
Tomato	4	2	50.00	37	10	27.02	3-5/2-5
Okra	2	1	50.00	20	04	20.00	2-5/2-5
Cucumber	2	2	100.00	18	03	16.66	2-5/2-5
Cauliflower	1	-	-	05	-	-	-
Cabbage	1	-	-	08	-	-	-

* GI = Gall index ; EMI = Egg mass index.

frequnecy was found for *M. incognita* and *M. arenaria* combination (3.70%) in Dehradun proper locality. Among the localities, frequency of *M. arenaria* + *M. hapla* (75%) was greater in Dehradun proper than any other combination in any locality. However, frequency of *M. incognita* + *M. arenaria* was 100% in Dehradun proper, since this combination was present only in this locality (Table 18).

Frequency of the species in total infected samples

Frequency of *M. incognita* was greater in total infected root samples than *M. javanica*, *M. hapla* and *M. arenaria* in all the localities. Lowest frequency was observed for *M. arenaria* (16.66%) in Rishikesh (Table 19).

Among the localities, all the species were more frequent in Dehradun proper than in other localities. Lowest frequency was observed for *M. hapla* (23.80%) in Doiwala (Table 19).

Identity and frequency of the races

Races 1, 2 and 4 of *M. incognita*; races A and B of *M. javanica* and race 2 of *M. arenaria* were recorded from the district. Race 3 of *M. incognita* and race 1 of *M. arenaria* were not present in the district (Fig. 6). Race 1 of *M. incognita* and race A of *M. javanica* were greater in frequency than other races of respective species in all the localities. Frequency of race 2 of *M. arenaria* was 100% in all the localities as it was the only race present.

Among the localities, race 1 (42.86%) of *M. incognita* was more frequent in Rishikesh than in other localities. Similarly race 2 (35.71%) was more frequent in Dehradun proper and Rishikesh than in Doiwala locality. Frequency of race 4 was 100% in Dehradun proper because this race was present only in this locality.

Table 18. Frequency of occurrence of species (%) of the root-knot nematodes in single and mixed populations on vegetable crops in different localities of Dehradun district

Locality	Frequency of species									
	Single population				Mixed population					
	Mi	Mj	Ma	Mh	Mi+Mj	Mi+Ma	Mi+Mh	Mj+Ma	Ma+Mh	Mi+Mj+Ma
Dehradun	25.92*	18.51	-	14.81	11.11	3.70	7.40	-	11.11	7.40
proper	(58.33)**	(62.50)		(57.14)	(37.50)	(100.00)	(20.00)		(75.00)	(28.57)
Rishikesh	27.77	5.55	-	16.66	11.11	-	22.22	-	-	16.66
	(41.66)	(12.50)		(42.85)	(25.00)		(40.00)			(42.85)
Doiwala	-	16.66	-	-	25.00	-	33.33	-	8.33	16.66
		(25.00)			(37.50)		(40.00)		(25.00)	(28.57)

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria;* Mh = *M. hapla.*

Table 19. Frequency of occurrence of the species (%) of root-knot nematodes in different localities of Dehradun district based on total infected root samples of vegetables

Locality	Total infected root samples	No. of root samples infected (Single +Mixed population)				Frequency of species in total infected samples			
		Mi	Mj	Ma	Mh	Mi	Mj	Ma	Mh
Dehradun proper	27	15	10	06	09	55.55*	37.03	22.22	33.33
						(39.47)**	(43.47)	(50.00)	(42..85)
Rishikesh	18	14	06	03	07	77.77	33.33	16.66	38.88
						(36.84)	(26.08)	(25.00)	(33.33)
Doiwala	12	09	07	03	05	75.00	58.33	25.00	41.66
						(23.68)	(30.43)	(25.00)	(23.80)

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria*; Mh = *M. hapla.*

Table 20. Frequency of occurrence of races of *Meloidogyne incognita* (Mi), *Meloidogyne javanica* (Mj) and *Meloidogyne arenaria* (Ma) in different localities of Dehradun district

Locality	Species/ Races	Frequency (%) of the races of *Mi*				Frequency (%) of the races of *Mj*		Frequency (%) of the races of *Ma*	
		R_1	R_2	R_3	R_4	A	B	R_1	R_2
Dehradun proper	Mi_{R1}, Mi_{R2}, Mi_{R4},	46.67*	33.33	-	20.00	70.00	30.00	-	100.00
	Mj_A, Mj_B, Ma_{R2},	(33.33)**	(35.71)		(100.00)	(43.75)	(42.86)		(50.00)
Rishikesh	Mi_{R1}, Mi_{R2},	64.29	35.71	-	-	66.67	33.33	-	100.00
	Mj_A, Mj_B, Ma_{R2},	(42.86)	(35.71)			(25.00)	(28.57)		(25.00)
Doiwala	Mi_{R1}, Mi_{R2},	55.56	44.44	-	-	71.43	28.57	-	100.00
	Mj_A, Mj_B, Ma_{R2},	(23.81)	(28.57)			(31.25)	(28.57)		(25.00)

* Values in rows represent frequency (%) of the races in the same locality.

** Values in parentheses in the columns of the races represent frequency (%) of the races of in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

R_1 = race 1; R_2 = race 2; R_3 = race 3 and R_4 = race 4 of *M. incognita* or *M. arenaria.*

A = race A and B = race B of *M. javanica.*

Race A (43.75%) and B (42.86%) of *M. javanica* were more frequent in Dehradun proper. Lowest frequency of race A (25%) was found in Rishikesh. *M. arenaria*, race 2 (50%) was also frequent in Dehradun proper (Table 20).

FARRUKHABAD

Incidence and Intensity of the Disease

Survey was conducted in three localities of the Farrukhabad district namely, Farrukhabad proper, Kaimganj and Jalalabad (Fig. 6). In the localities of Farrukhabad district, 50-67% fields of vegetables were infested with root-knot nematodes. The incidence of the disease was highest in Farrukhabad proper (67%) followed by Kaimganj (57%) and Jalalabad (50%) (Table 21). On root samples basis, frequency of root-knot disease was highest in Jalalabad (48%) followed by Farrukhabad proper (41%). In Kaimganj, frequency was only 34 per cent (Table 21).

Highest intensity of the disease, on the basis of gall index (GI) and egg mass index (EMI) was observed in Kaimganj, being moderate to severe (3-5/2-5). In Farrukhabad proper and Jalalabad localities, intensity was mild to very severe (2-5/2-5) (Table 21).

Incidence of the disease was highest (100%) in the cabbage fields. Frequency of the disease in the fields of eggplant, tomato, okra, and cauliflower was 80, 75, 50 and 50%, respectively. Lowest frequency (35%) was in the pepper fields. Cucumber fields were found free from infestation (Table 22).

Highest frequency was observed in the root samples of eggplant (73.91%) followed by tomato (45%), okra (33.33%), pepper (27.5%), cabbage (25%) and cauliflower (15%) (Table 22).

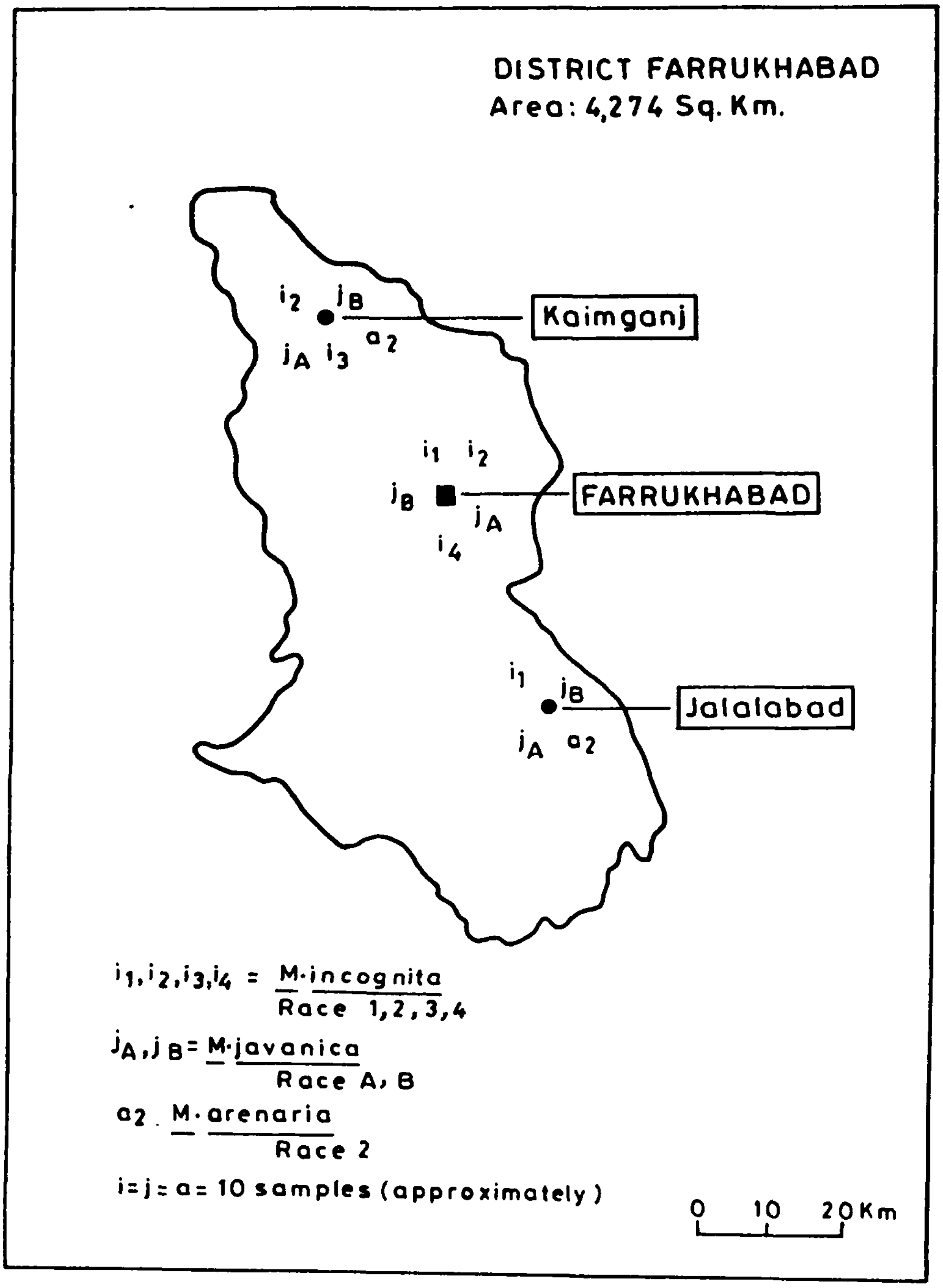

Fig. 6. Distribution of *Meloidogyne* species and their races in Farrukhabad district.

Table 21. Incidence and intensity of root-knot nematodes on vegetable crops in different localities of Farrukhabad district

Locality	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Farrukhabad proper	6	4	66.66	60	25	41.11	2-5/2-5
Kaimganj	7	4	57.14	56	19	33.92	3-5/2-5
Jalalabad	6	3	50.00	63	30	47.61	2-5/2-5
Total	19	11	57.89	179	74	41.34	2-5/2-5

* GI = Gall index; EMI = Egg mass index.

Intensity of the disease was generally severe to very severe on eggplant as GI/EMI were 4-5/4-5. GI and EMI, both ranged between 3 and 5 on pepper, between 2 and 5 on okra and cabbage, and between 1 and 5 on cauliflower roots (Table 22).

Identity of the species

M. incognita, M. javanica and *M. arenaria* were found infesting the vegetable fields in the district. They were present either in single or in mixed populations in the localities of the district surveyed (Fig. 6, Table 22).

Frequency of the species in single and mixed populations

Frequency of single population of *M. incognita* was greater than *M. javanica* and *M. arenaria* in all the localities. Lowest frequency was observed for *M. arenaria*. It was 13.33% and 15.78% in Jalalabad and Kaimganj, respectively (Table 23). When frequency of a species was compared among the localities, it emerged that all the species were more frequent in the Jalalabad than other localities of the district (Table 23).

In Farrukhabad proper, *M. incognita* and *M. javanica* alone were found in mixed populations. In Kaimganj, two species combination of the three species was found. Frequency of *M. incognita* + *M. javanica* (26.31%) combination was greater than *M. incognita* + *M. arenaria* (10.52%) and *M. javanica* + *M. arenaria* (10.52%) combinations. In Jalalabad, frequency of *M. incognita* + *M. arenaria* (10%) combination was greater than *M. javanica* + *M. arenaria* (6.66%) combination. *M. incognita* + *M. javanica* + *M. arenaria* combination was not observed in any locality of the district (Table 23).

Among the localities, *M. incognita* + *M. javanica* (61.53%) combination was higher in Farrukhabad proper, and *M. incognita* + *M.*

Table 22. Incidence and intensity of root-knot nematodes on different vegetable crops in Farrukhabad district

Crop	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Pepper	4	1	25.00	40	11	27.50	3-5/3-5
Eggplant	5	4	80.00	46	34	73.91	4-5/4-5
Tomato	4	3	75.00	40	18	45.00	3-5/3-5
Okra	2	1	50.00	18	06	33.33	2-5/2-5
Cucumber	1	-	-	07	-	-	-
Cauliflower	2	1	50.00	20	30	15.00	1-5/1-5
Cabbage	1	1	100.00	08	02	25.00	2-5/2-5

* GI = Gall index ; EMI = Egg mass index.

arenaria (60%) and *M. javanica* + *M. arenaria* combinations in Jalalabad (Table 23).

Frequency of the species in total infected samples

In total infected root samples, frequency of *M. incognita* was greater than *M. javanica* in all the localities. Frequency of *M. arenaria* (36.84%) equalled with *M. javanica* (36.84%) in Kaimganj (Table 24).

Among the localities, frequencies of *M. incognita* (37.50%) and *M. javanica* (46.87%) were highest in Farrukhabad proper and of *M. arenaria* (56.25%) in Jalalabad (Table 24).

Identity and frequency of the races

All the four races of *M. incognita* (races 1, 2, 3 and 4); race A and race B of *M. javanica* and race 2 of *M. arenaria* were recorded in the district (Fig. 6, Table 25). But their distribution and frequency varied. Race 1 of *M. incognita* was more frequent than race 2 and race 4 in Farrukhabad proper, and race 2 than race 3 in Kaimganj. Race 1 was the only race observed in *M. incognita* populations in Jalalabad.

Among the localities, frequency of race 1 (69.57%) of *M. incognita* was highest in Jalalabad and of race 2 (61.54%) in Kaimganj. Frequencies of race 3 in Kaimganj and of race 4 in Farrukhabad proper was 100% (Table 25).

In *M. javanica* populations, race A was more frequent than race B in all the localities. Both the races showed greater frequency in Farrukhabad proper than in other localities (Table 25).

In *M. arenaria* populations only race 2 was present in the district. Therefore, its frequency was 100% in the two localities where it was found. Among the localities, its frequency was greater in Jalalabad (56.25%) than Kaimganj (43.75%) (Table 25).

Table 23. Frequency of occurrence of species (%) of the root-knot nematodes in single and mixed populations on vegetable crops in different localities of Farrukhabad district

Locality	Frequency of species						
	Single population			Mixed population			
	Mi	Mj	Ma	Mi+Mj	Mi+Ma	Mj+Ma	Mi+Mj+Ma
Farrukhabad	40.00*	28.00	-	32.00	-	-	-
proper	(33.33)**	(46.66)		(61.53)			
Kaimganj	36.82	-	15.78	26.31	10.52	10.52	-
	(23.33)		(42.85)	(28.46)	(40.00)	(40.00)	
Jalalabad	43.33	26.66	13.33	-	10.00	6.66	-
	(43.33)	(53.33)	(57.14)		(60.00)	(50.00)	

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

Table 24. Frequency of occurrence of the species (%) of root-knot nematodes in different localities of Farrukhabad district on total infected root samples of vegetables

Locality	Total infected root samples	No. of root samples infected (Single +Mixed population)			Frequency of species in total infected samples		
		Mi	Mj	Ma	Mi	Mj	Ma
Farrukhabad Proper	25	18	15	-	72.00* (37.50)**	60.00 (46.87)	-
Kaimganj	19	14	07	07	73.68 (29.16)	36.84 (21.87)	36.84 (43.75)
Jalalabad	30	16	10	09	53.33 (33.33)	33.33 (31.25)	30.00 (56.25)

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

Table 25. Frequency of occurrence of races of *Meloidogyne incognita* (Mi), *Meloidogyne javanica* (Mj) and *Meloidogyne arenaria* (Ma) in different localities of Farrukhabad district

Locality	Species/ Races	Frequency (%) of the races of *Mi*				Frequency (%) of the races of *Mj*		Frequency (%) of the races of *Ma*	
		R_1	R_2	R_3	R_4	A	B	R_1	R_2
Farrukhabad proper	Mi_{R1}, Mi_{R2}, Mi_{R4}, Mj_A, Mj_B,	38.89* (30.43)**	27.27 (38.46)	-	33.33 (100.00)	73.33 (50.00)	26.67 (40.00)	-	-
Kaimganj	Mi_{R2}, Mi_{R3},	-	57.14	42.86	-	57.14	42.86	-	100.00
	Mj_A, Mj_B, Ma_{R2},		(61.54)	(100.00)		(18.18)	(30.00)		(43.75)
Jalalabad	Mi_{R1},	100.00	-	-	-	70.00	30.00	-	100.00
	Mj_A, Mj_B, Ma_{R2},	(69.57)				(31.82)	(30.00)		(56.25)

* Values in rows represent frequency (%) of the races in the same locality.

** Values in parentheses in the columns of the races represent frequency (%) of the races of in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

R_1 = race 1; R_2 = race 2; R_3 = race 3 and R_4 = race 4 of *M. incognita* or *M. arenaria.*

A = race A and B = race B of *M. javanica.*

HARDOI

Incidence and intensity of the disease

In Hardoi district, three localities, Hardoi proper, Shahabad and Sandila (Fig. 7) were surveyed. The per cent infestation in vegetable fields of different localities varied from 40 to 60%. Incidence of the disease was highest in Shahabad (60%) followed by Sandila (57.14%) and Hardoi proper (40%) (Table 26). On the root sample basis, the incidence was also highest in Shahabad (46.66%) than Sandila (35.71%) and Hardoi proper (30%) (Table 26). Gall index (GI) ranged between 2 and 5 and egg mass index between 1 and 5 in the localities (Table 26).

Among the vegetables, incidence of the disease was highest in eggplant fields (80%) followed by tomato and cabbage fields showing 50% incidence of the disease. The incidence was lowest in cucumber fields (33.33%). Okra and cauliflower fields were found free from infestation (Table 27). The incidence of the disease on roots was highest on eggplant (62.22%) followed by tomato (41.66%), cucumber (35%) and pepper (30.43%). Lowest incidence was found on cabbage (14.28%) (Table 27).

Highest intensity based on GI and EMI was observed on eggplant roots (4-5/4-5) followed by tomato (3-5/3-5). On other vegetables, GI/EMI range was 2-5/1-5 (Table 27).

Identity of the species

M. incognita, M. javanica and *M. arenaria* were found to be present in Hardoi district (Fig. 7, Table 28). All the three species were found singly or concomitantly on roots of the vegetables. Mixed populations of *M. incognita* + *M. javanica; M. incognita* + *M. arenaria; M. javanica* + *M. arenaria* and *M. incognita* + *M. javanica* + *M. arenaria* were found (Table 28).

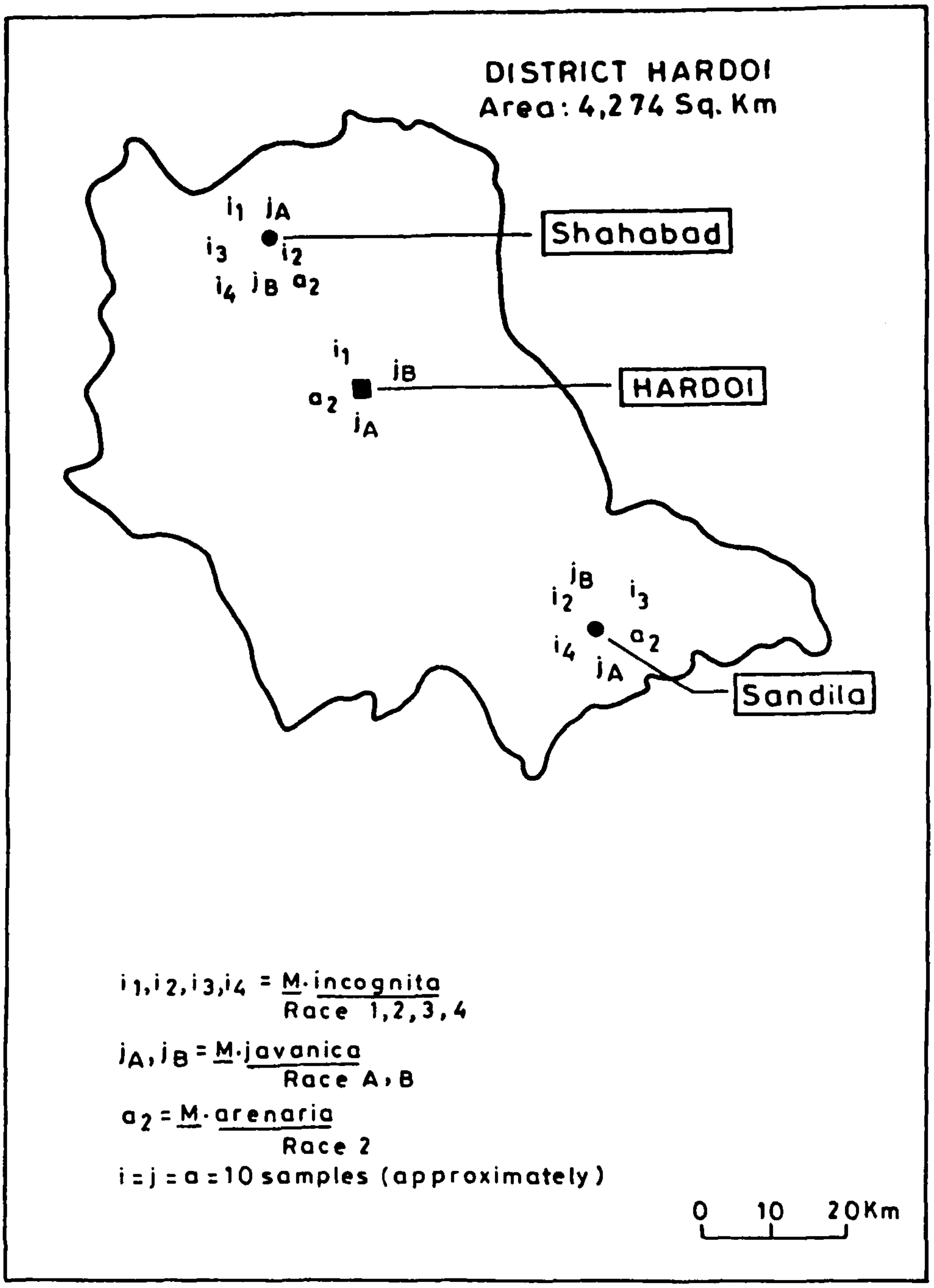

Fig. 7. Distribution of *Meloidogyne* species and their races in Hardoi district.

Table 26. Incidence and intensity of root-knot nematodes on vegetable crops in different localities of Hardoi district

Locality	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Hardoi proper	10	4	40.00	50	15	30.00	2-5/1-5
Shahabad	5	3	60.00	45	21	46.66	3-5/3-5
Sandila	7	4	50.00	70	25	35.71	3-5/3-5
Total	22	11	52.34	165	61	36.96	2-5/1-5

* GI = Gall index; EMI = Egg mass index.

Table 27. Incidence and intensity of root-knot nematodes on different vegetable crops in Hardoi district

Crop	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Pepper	6	3	50.00	46	14	30.43	2-5/1-5
Eggplant	5	4	80.00	45	28	62.22	4-5/4-5
Tomato	4	2	50.00	24	10	41.66	3-5/3-5
Okra	1	-	-	07	-	-	-
Cucumber	3	1	33.33	20	07	35.00	2-5/2-5
Cauliflower	1	-	-	09	-	-	-
Cabbage	2	1	50.00	14	02	14.28	2-5/2-5

* GI = Gall index; EMI = Egg mass index.

Frequency of the species in single and mixed populations

Single populations of *M. incognita* were observed in Shahabad and Sandila; of *M. javanica* in Hardoi proper and of *M. arenaria* in Shahabad localities. Frequency of *M. incognita* (40%) was greater in Shahabad (38%) than *M. arenaria* (4.76%).

Among the localities, frequency of *M. incognita* (55.55%) was greater in Sandila than in Shahabad (44.44%). As *M. javanica* was present only in Hardoi proper and *M. arenaria* in Shahabad, their frequencies were 100% (Table 28).

In mixed populations, *M. incognita* with *M. javanica* or *M. incognita* with *M. arenaria* or *M. javanica* with *M. arenaria* or *M. incognita* with *M. javanica* and *M. arenaria* were present on roots of the vegetables collected. The frequency of *M. incognita* and *M. javanica* was greater in all the localities than other combinations. The lowest frequency was observed for *M. incognita* + *M. javanica* + *M. arenaria* combination (8%) in Sandila (Table 28).

Within three localities, frequency of mixed populations of *M. incognita* + *M. javanica* (38.88%) and *M. incognita* + *M. arenaria* (75%) in Sandila; *M. javanica* + *M. arenaria* (60%) and all the three species populations (66.66%) in Shahabad locality was highest (Table 28).

Frequency of the species in total infected samples

In total infected samples, frequency of *M. javanica* (86.66%) in Hardoi proper and of *M. incognita* (80.95%) in Shahabad and Sandila was greater than other species in the localities (Table 29).

Frequency of *M. incognita* (50%) between the localities was highest in Sandila and of *M. javanica* (38.23%) in Hardoi proper.

Table 28. Frequency of occurrence of species (%) of the root-knot nematodes in single and mixed populations on vegetable crops in different localities of Hardoi district

Locality	Frequency of species						
	Single population			Mixed population			
	Mi	Mj	Ma	Mi+Mj	Mi+Ma	Mj+Ma	Mi+Mj+Ma
Hardoi proper	-	33.33*	-	40.00	13.33	13.33	-
		(100.00)**		(33.33)	(25.00)	(40.00)	
Shahabad	38.09	-	4.76	23.80	-	14.28	19.04
	(44.44)		(100.00)	(27.77)		(60.00)	(66.66)
Sandila	40.00	-	-	28.00	24.00	-	8.00
	(55.55)			(38.88)	(75.00)		(33.33)

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

Table 29. **Frequency of occurrence of species (%) of root-knot nematodes in different localities of Hardoi district on total infected root samples of vegetables**

Locality	Total infected root samples	No. of root samples infected (Single +Mixed population)			Frequency of species in total infected samples		
		Mi	Mj	Ma	Mi	Mj	Ma
Hardoi proper	15	08	13	04	53.33*	86.66	26.66
					(16.00)**	(38.23)	(20.00)
Shahabad	21	17	12	08	80.95	57.14	38.09
					(34.00)	(35.29)	(40.00)
Sandila	25	25	09	08	100.00	36.00	32.00
					(50.00)	(26.47)	(40.00)

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

Frequency of *M. arenaria* was equal (40%) in Shahabad and Sandila localities (Table 29).

Identity and frequency of the races:

Races 1, 2, 3, and 4 of *M. incognita*, race A and B of *M. javanica* and race 2 of *M. arenaria* were recorded from the district (Fig. 7, Table 30). In Hardoi proper, only race 1 of *M. incognita* was recorded. So its frequency was 100%. Frequency of race 1 (47.06%) in Shahabad and of race 2 (48%) in Sandila was greater than other races (Table 30).

Among the localities, race 1 (50%) of *M. incognita* was equally frequent in Hardoi proper and Shahabad. Frequencies of race 2 (75%); race 3 (66.67%) and race 4 (77.77%) were higher in Sandila as compared to Shahabad (Table 30).

In *M. javanica* populations, race A was more frequent than race B in all the localities of the district. Frequency of race A of *M. javanica* (43.48%) was highest in Hardoi proper and of race B (45.45%) in Shahabad (Table 30).

In, *M. arenaria* populations only race 2 was present in the district. Therefore, its frequency was (100%) in its population in all three localities. Among the localities, its frequency in Shahabad and Sandila was equal (40%). In Hardoi proper, its frequency was 20% (Table 30).

SITAPUR

Incidence and intensity of the disease

In the Sitapur district, three localities viz., Sitapur proper, Sadarpur and Hargaon were surveyed (Fig. 8). About 53.84% vegetables fields were infested with root-knot nematodes in the localities; highest being in Sadarpur (62.50%). In Hargaon and Sitapur proper, the incidence was 55.55% and 44.44%, respectively (Table 31).

Table 30. **Frequency of occurrence of races of *Meloidogyne incognita* (Mi), *Meloidogyne javanica* (Mj) and *Meloidogyne arenaria* (Ma) in different localities of Hardoi district**

Locality	Species/ Races	Frequency (%) of the races of *Mi*				Frequency (%) of the races of *Mj*		Frequency (%) of the races of *Ma*	
		R_1	R_2	R_3	R_4	A	B	R_1	R_2
Hardoi proper	Mi_{R1},	100.00*	-	-	-	76.92	23.08	-	100.00
	Mj_A, Mj_B, Ma_{R2},	(50.00)**				(43.48)	(27.27)		(20.00)
Shahabad	Mi_{R1},Mi_{R2},Mi_{R3},Mi_{R4},	47.06	23.53	17.65	11.76	58.33	41.67	-	100.00
	Mj_A, Mj_B, Ma_{R2},	(50.00)	(25.00)	(33.33)	(22.22)	(30.43)	(45.45)		(40.00)
Sandila	Mi_{R2},Mi_{R3},Mi_{R4},	-	48.00	24.00	28.00	66.67	33.33	-	100.00
	Mj_A, Mj_B, Ma_{R2},		(75.00)	(66.67)	(77.77)	(26.09)	(27.27)		(40.00)

* Values in rows represent frequency (%) of the races in the same locality.

** Values in parentheses in the columns of the races represent frequency (%) of the races of in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

R_1 = race 1; R_2 = race 2; R_3 = race 3 and R_4 = race 4 of *M. incognita* or *M. arenaria.*

A = race A and B = race B of *M. javanica.*

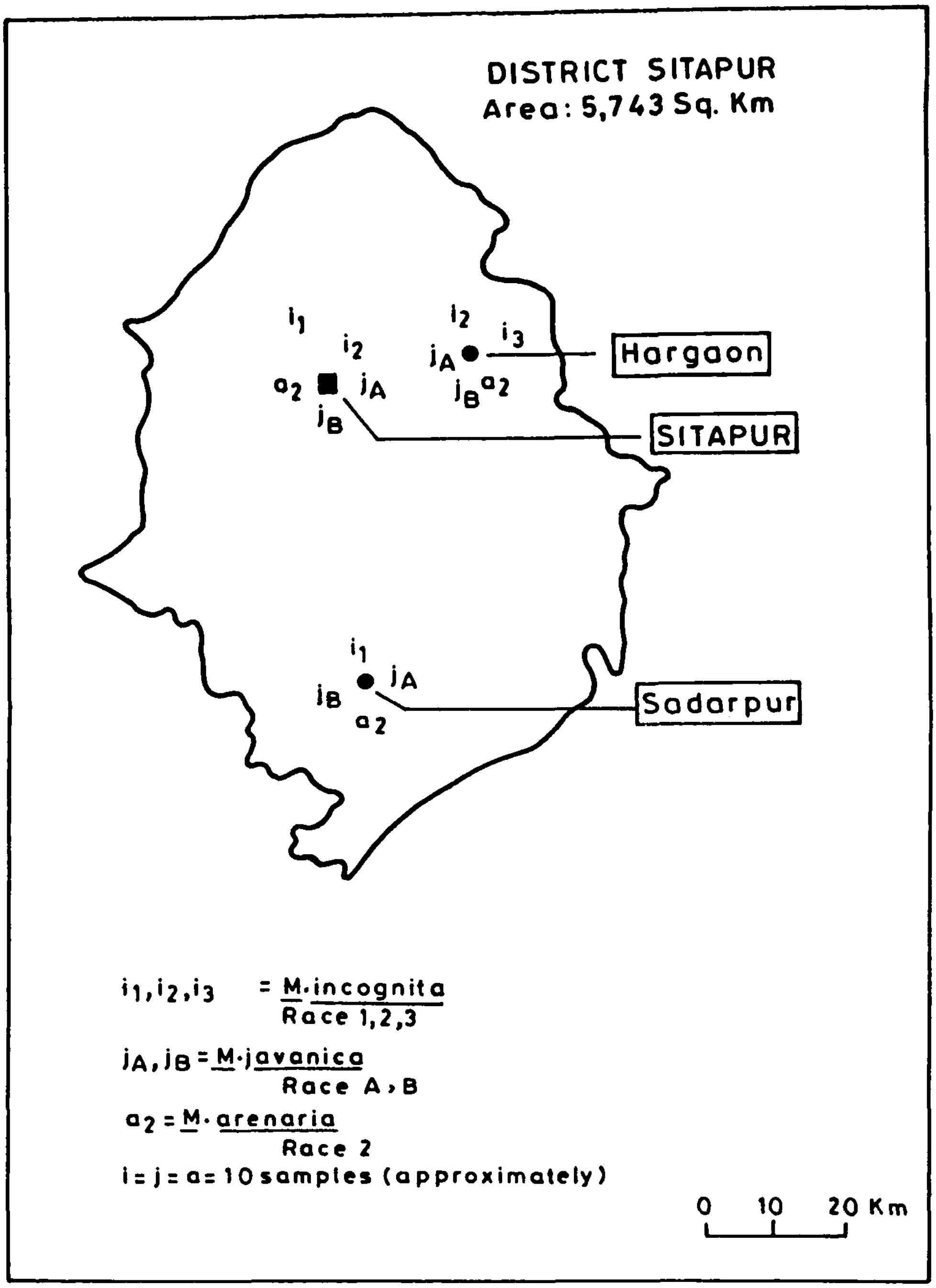

Fig. 8. Distribution of *Meloidogyne* species and their races in Sitapur district.

The frequency of occurrence of the disease on the root sample basis was highest in Sadarpur (41.66%) closely followed by Sitapur proper (40%) (Table 31).

The disease intensity was very severe (3-5/3-5) in Sitapur proper; mild to very severe (2-5/2-5) in Sadarpur and very mild to severe (1-5/1-5) in Hargaon. Highest incidence of the disease was observed in eggplant fields (80%) followed by pepper (66.66%). In tomato, okra, and cauliflower fields, the incidence was 50% and in cucumber fields 40%. The lowest incidence was (33.33%) was in cabbage fields. (Table 32).

The frequency of occurrence of the disease, on the root sample basis, was highest on eggplant (68.88%) followed by okra (45%). Lowest frequency was observed on cabbage (14.28%) and cauliflower (12.50%) (Table 32).

Intensity of the disease was found highest on eggplant (4-5/4-5) and lowest on cabbage (1-5/2-5) (Table 32).

Identity of the species

Three species of *Meloidogyne, M. incognita, M. javanica* and *M. arenaria* were identified to be present in the district (Fig. 8). Single population of all the three species and mixed population of *M. incognita* + *M. javanica; M. incognita* + *M. arenaria*; *M. javanica* + *M. arenaria* or of all the three species were encountered.

Frequency of the species in single and mixed populations

Frequency of single populations of *M. incognita* (36.11%) in Sitapur proper; of *M. arenaria* (33.33%) in Sadarpur; and of *M. javanica* in Hargaon (26.66%) was greater than other species (Table 33). *M. javanica* (57.14%) in Hargaon and *M. arenaria* (70%) in Sadarpur were most

Table 31. Incidence and intensity of root-knot nematodes on vegetable crops in different localities of Sitapur district

Locality	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Sitapur proper	9	4	44.44	90	36	40.00	3-5/3-5
Sadarpur	8	5	62.50	72	30	41.66	2-5/2-5
Hargaon	9	5	55.55	54	21	38.88	1-5/1-5
Total	26	14	53.84	216	87	40.27	1-5/1-5

* GI = Gall index; EMI = Egg mass index.

Table 32. Incidence and intensity of root-knot nematodes on different vegetable crops in Sitapur district

Crop	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Pepper	3	2	66.66	30	12	40.00	3-5/3-5
Eggplant	5	4	80.00	45	21	68.88	4-5/4-5
Tomato	4	2	50.00	36	15	41.66	2-5/2-5
Okra	2	1	50.00	20	09	45.00	2-5/2-5
Cucumber	5	2	40.00	40	14	35.00	3-5/2-5
Cauliflower	4	2	50.00	24	03	12.50	1-5/2-5
Cabbage	3	1	33.33	21	03	14.28	1-5/2-5

* GI = Gall index ; EMI = Egg mass index.

frequent among the localities. Since *M. incognita* was encountered only in Sitapur proper, its frequency was (100%) (Table 33).

Frequencies of mixed populations of *M. incognita* + *M. javanica* + *M. arenaria* in Sitapur proper (22.22%) and Sadarpur (23.80%) and of *M. incognita* + *M. javanica* in Hargaon (33.33%) were greater than other species combinations (Table 33).

Among the localities, frequencies of *M. incognita* and *M. javanica* (58.82%) in Hargaon and of *M. javanica* + *M. arenaria* (41.66%) and *M. incognita* + *M. arenaria* (50%) in Sitapur proper were highest as compared to other localities. *M. incognita* + *M. arenaria* combinations was present only is Hargaon (100%) (Table 33).

Frequency of the species in total infected samples

When the frequency of species in total infected root samples regardless of single or mixed populations was analysed, frequency of *M. incognita* was greater than *M. javanica* (55.55%) and *M. arenaria* (44.44%) in Sitapur proper. In Sadarpur, frequency of *M. javanica* (83.33%) was greater than *M. incognita* (60%) and *M. arenaria* (40%). The frequency of *M. arenaria* (71.42%) was more than *M. javanica* (66.66%) and *M. incognita* (23.80%) in Hargaon (Table 34).

Among the localities, on the basis of total root samples, frequencies of *M. incognita* (54.90%) and of *M. arenaria* (37.20%), were highest in Sitapur, and of *M. javanica* (42.37%) in Sadarpur (Table 34).

Identity and frequency of races

Races 1, 2 and 3 of *M. incognita*; races A and B of *M. javanica* and race 2 of *M. arenaria* were identified to be present in the district (Fig. 8, Table 35). Races 1 and 2 of *M. incognita* existed in

Table 33. Frequency of occurrence of species (%) of the root-knot nematodes in single and mixed populations on vegetable crops in different localities of Sitapur district

Locality	Frequency of species						
	Single population			Mixed population			
	Mi	Mj	Ma	Mi+Mj	Mi+Ma	Mj+Ma	Mi+Mj+Ma
Sitapur proper	36.11*	-	8.33	19.44	-	13.88	22.22
	(100.00)**		(30.00)	(41.17)		(41.66)	(50.00)
Sadarpur	-	28.57	33.33	-	-	14.28	23.80
		(42.85)	(70.00)			(25.00)	(31.25)
Hargaon	-	26.66	-	33.33	16.66	13.33	10.00
		(57.14)		(58.82)	(100.00)	(33.33)	(18.75)

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

Table 34. Frequency of occurrence of the species (%) of root-knot nematodes in different localities of Sitapur district based on total infected root samples of vegetables

Locality	Total infected root samples	No. of root samples infected (Single +Mixed population)			Frequency of species in total infected samples		
		Mi	**Mj**	**Ma**	**Mi**	**Mj**	**Ma**
Sitapur proper	36	28	20	16	77.77* (54.90)**	55.55 (37.20)	44.44
Sadarpur	30	18	25	12	60.00 (35.29)	83.33 (42.37)	40.00 (27.90)
Hargaon	21	05	14	15	23.80 (9.80)	66.66 (23.72)	71.42 (34.88)

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

Table 35. Frequency of occurrence of races of *Meloidogyne incognita* (Mi), *Meloidogyne javanica* (Mj) and *Meloidogyne arenaria* (Ma) in different localities of Sitapur district

Locality	Species/ Races	Frequency (%) of the races of *Mi*				Frequency (%) of the races of *Mj*		Frequency (%) of the races of *Ma*	
		R_1	R_2	R_3	R_4	A	B	R_1	R_2
Sitapur proper	Mi_{R1}, Mi_{R2},	78.57*	21.43	-	-	65.00	35.00	-	100.00
	Mj_A, Mj_B, Ma_{R2},	(81.48)**	(42.86)			(65.00)	(35.00)		(37.21)
Sadarpur	Mi_{R2}, Mi_{R3},	-	44.44	55.56	-	68.00	32.00	-	100.00
	Mj_A, Mj_B, Ma_{R2},		(57.14)	(100.00)		(42.50)	(26.11)		(27.91)
Hargaon	Mi_{R1},	100.00	-	-	-	71.43	28.57	-	100.00
	Mj_A, Mj_B, Ma_{R2},	(18.52)				(25.00)	(21.05)		(34.88)

* Values in rows represent frequency (%) of the races in the same locality.

** Values in parentheses in the columns of the races represent frequency (%) of the races of in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

R_1 = race 1; R_2 = race 2; R_3 = race 3 and R_4 = race 4 of *M. incognita* or *M. arenaria.*

A = race A and B = race B of *M. javanica.*

Sitapur proper and their frequencies were 78.57% and 21.43%, respectively. Race 2 and race 3 of *M. incognita* were observed in Sadarpur and their frequencies were 44.44% and 55.56%, respectively. In Hargaon, only race 1 was present, so its frequency was 100% (Table 35).

Among the localities, frequency of race 1 (81.48%) was highest in Sitapur and race 2 (57.14%) in Sadarpur as compared to other localities. Frequency of race 3 was 100% in Sadarpur because race 3 was not present in other two localities (Table 35).

In *M. javanica* populations, race A was more frequent than race B in all the localities. When frequency of the races was compared between localities, race A (42.50%) was more frequent in Sadarpur and race B (36.84%) in Sitapur proper than other localities (Table 35).

In *M. arenaria* populations, only race 2 was present in the district. Therefore, its frequency was 100% in all the localities. Among the localities, its frequency was greater in Sitapur proper (37.21%) followed by in Hargaon (34.88%) and in Sadarpur (27.91%) (Table 35).

BASTI

Incidence and intensity of the disease

Basti proper, Khalilabad, and Dumariaganj were three localities which were included in the survey of the Basti district (Fig. 9). Incidence of disease was highest in Basti proper (71.42%) followed by Khalilabad (50%) and Dumariaganj (40%). Average incidence of the disease recorded for the district was 55% (Table 36). When frequency of occurrence of the disease was assessed on root sample basis, it emerged that, 46.87% root samples from Basti proper, 39.58% from Khalilabad and 30% from Dumariaganj were infected.

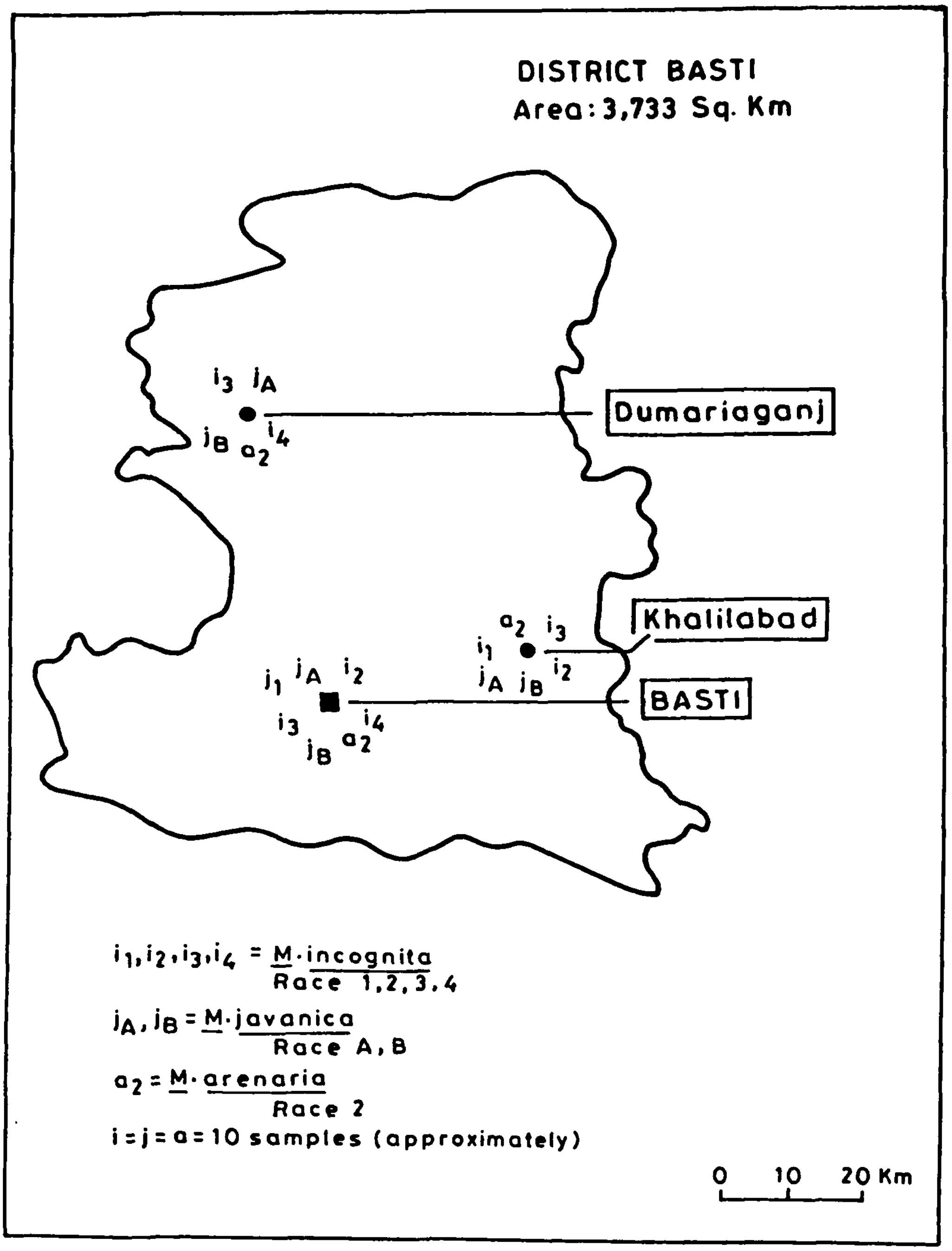

Fig. 9. Distribution of *Meloidogyne* species and their races in Basti district.

Highest intensity of the disease was observed in Dumariaganj (3-5/3-5). The intensity was mild to very severe (2-5/2-5) in Basti proper and very mild to severe (1-5/1-5) in Khalilabad (Table 36).

Among the vegetable crops, the incidence was highest in eggplant and okra fields (100%) followed by cauliflower (60%), pepper (50%) and tomato (50%) fields. Cabbage and cucumber fields surveyed were found free from infestation (Table 36). The incidence of the disease was highest on eggplant (74.07%) followed by tomato (62.50%), okra (55.55%) and pepper roots (47.50%). Lowest incidence was observed on cauliflower roots (22.22%) (Table 37).

Intensity of the disease on different vegetables showed variations. Highest intensity range, (severe to very severe) was found on eggplant and tomato as GI/EMI were 4-5/4-5 or 4-5/3-5. Intensity range, moderate to very severe (3-5/3-5) was found on pepper and okra. On cauliflower roots, GI/EMI was 2-5/1-5 (Table-37).

Identity of the species

From the district, *M. incognita, M. javanica* and *M. arenaria* were identified to be present on different vegetables (Fig. 9, Table 38). Single population of *M. incognita* or *M. javanica* and mixed populations of *M. incognita+ M. javanica* or *M. javanica + M. arenaria* or of all the three species were recorded (Table 38).

Frequency of the species in single and mixed populations

In single populations, frequency of *M. incognita* was greater than *M. javanica* in all the localities. *M. arenaria* was not encountered in single population in any locality (Table 38). Among the localities, *M. incognita* (44%) and *M. javanica* (80%) were highly frequent in Basti proper as compared to other localities (Table 38).

Table 36. Incidence and intensity of root-knot nematodes on vegetable crops in different localities of Basti district

Locality	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Basti proper	7	5	71.42	64	30	46.87	2-5/2-5
Khalilabad	6	3	50.00	48	19	39.58	1-5/1-5
Dumariaganj	5	2	40.00	50	15	30.00	3-5/3-5
Total	18	10	55.55	162	64	39.50	1-5/1-5

* GI = Gall index; EMI = Egg mass index.

Table 37. Incidence and intensity of root-knot nematodes on vegetable crops in Basti district

Crop	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Pepper	4	2	50.00	40	19	47.50	3-5/3-5
Eggplant	3	3	100.00	27	20	74.07	4-5/4-5
Tomato	2	1	50.00	16	10	62.50	4-5/3-5
Okra	1	1	100.00	09	05	55.55	3-5/3-5
Cucumber	2	-	-	18	-	-	-
Cauliflower	5	3	60.00	45	10	22.22	2-5/1-5
Cabbage	1	-	-	07	-	-	-

* GI = Gall index; EMI = Egg mass index.

In Basti proper and Dumariaganj, mixed populations of *M. incognita* + *M. javanica* was greater than other combinations, while in Khalilabad frequency of *M. javanica* + *M. arenaria* (26.31%) was greater than *M. incognita* + *M. javanica* + *M. arenaria* (21.05%) and *M. incognita* + *M. javanica* (10.52%) combinations (Table 38). Among the localities, frequency of *M. incognita* + *M. javanica* (50%) in Basti proper and *M. javanica* + *M. arenaria* (45.45%) in Khalilabad was highest. *M. incognita* + *M. arenaria* and *M. incognita* + *M. javanica* + *M. arenaria* combinations were recorded only from Basti and Khalilabad localities respectively, therefore their frequencies were 100% (Table 38).

Frequency of the species in total infected samples

In total infected root samples, frequency of *M. incognita* was greater than other two species in all the localities. Similarly *M. javanica* was more frequent than *M. arenaria* in all the localities (Table 39). When frequency of occurrence of the same species in different localities was compared, it was found that frequency of *M. incognita* (47.91%) and *M. javanica* (41.17%) was highest in Basti proper and of *M. arenaria* (45%) in Khalilabad locality (Table 39).

Identity and frequency of the races

All the four races of *M. incognita* viz; (races 1, 2, 3 and 4); two races of *M. javanica* *viz.*, (races A and B) and race 2 of *M. arenaria* were found in the district (Fig. 9). In Basti proper and Khalilabad, frequency of race 1 of *M. incognita* (34.78%) was greater than other races of the species. In Dumariaganj, frequency of race 3 (54.55%) of *M. incognita* was greater than race 4 (45.45%) (Table 40).

Among the localities, frequency of race 1 (53.33%) and race 2 (54.55%) of *M. incognita* were highest in Basti proper and race 3 (40%), and race 4 (55.56%) in Dumariaganj (Table 40).

Table 38. Frequency of occurrence of species (%) of the root-knot nematodes in single and mixed populations on vegetable crops in different localities of Basti district

Locality	Frequency of species						
	Single population			Mixed population			
	Mi	Mj	Ma	Mi+Mj	Mi+Ma	Mj+Ma	Mi+Mj+Ma
Basti proper	36.66*	13.33	-	23.33	16.66	10.00	-
	(44.00)**	(80.00)		(50.00)	(100.00)	(27.27)	
Khalilabad	42.10	-	-	10.52	-	26.31	21.05
	(32.00)			(14.28)		(45.45)	(100.00)
Dumariaganj	40.00	6.66	-	33.33	-	20.00	-
	(24.00)	(20.00)		(35.71)		(27.27)	

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

Table 39. Frequency of occurrence of species (%) of root-knot nematodes in different localities of Basti district based on total infected root samples of vegetables

Locality	Total infected root samples	No. of root samples infected (Single +Mixed population)			Frequency of species in total infected samples		
		Mi	Mj	Ma	Mi	Mj	Ma
Basti proper	30	23	14	08	76.66*	46.66	26.66
					(47.91)**	(41.17)	(40.00)
Kahalilabad	19	14	11	09	73.68	57.89	47.36
					(29.16)	(32.35)	(45.00)
Dumariaganj	15	11	09	03	73.33	60.00	20.00
					(22.91)	(26.47)	(15.00)

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

Table 40. Frequency of occurrence of races of *Meloidogyne incognita* (Mi), *Meloidogyne javanica* (Mj) and *Meloidogyne arenaria* (Ma) in different localities of Basti district

Locality	Species/ Races	Frequency (%) of the races of *Mi*				Frequency (%) of the races of *Mj*		Frequency (%) of the races of *Ma*	
		R_1	R_2	R_3	R_4	A	B	R_1	R_2
Basti proper	Mi_{R1},Mi_{R2},Mi_{R3},Mi_{R4}	34.78*	26.09	21.74	17.39	71.43	28.57	-	100.00
	Mj_A, Mj_B, Ma_{R2},	(53.33)**	(54.55)	(38.46)	(44.44)	(41.67)	(40.00)		(40.00)
Khalilabad	Mi_{R1},Mi_{R2},Mi_{R3}	50.00	35.71	14.29	-	63.64	36.36	-	100.00
	Mj_A, Mj_B, Ma_{R2},	(46.67)	(45.45)	(15.38)		(29.17)	(40.00)		(45.00)
Dumariaganj	Mi_{R3},Mi_{R4},	-	-	54.55	45.45	77.78	22.22	-	100.00
	Mj_A, Mj_B, Ma_{R2},			(40.00)	(55.56)	(29.17)	(20.00)		(15.00)

* Values in rows represent frequency (%) of the races in the same locality.

** Values in parentheses in the columns of the races represent frequency (%) of the races of in different localities.

Mi = *M. incognita*; Mj = *M. javanica*; Ma = *M. arenaria*.

R_1 = race 1; R_2 = race 2; R_3 = race 3 and R_4 = race 4 of *M. incognita* or *M. arenaria*.

A = race A and B = race B of *M. javanica*.

In *M. javanica* populations, race A was more frequent than race B in all the localities (Table 40). When frequency of the same race was compared between localities, it appeared that frequency of race A (41.67%) was highest in Basti proper and of race B (40%) also in Basti proper and in Khalilabad localities, lowest being in Dumariaganj (20%) (Table 40).

In *M. arenaria* populations only race 2 was present in the district. Therefore, its frequency was (100%) in all the localities. Among the localities, its frequency was greater in Khalilabad (45%) followed by in Basti proper (40%) and in Dumariaganj (25%) (Table 40).

GORAKHPUR

Incidence and intensity of the species

Root samples of vegetable crops were collected from three localities namely Gorakhpur proper, Maharajganj and Gola Bazar of the Gorakhpur district (Fig. 10, Table 41) to assess the incidence and intensity of the disease in vegetable fields in the district. The incidence of the disease ranged between 50-57.14%. Highest frequency was in Gorakhpur proper (57.14%) followed by Gola Bazar (55.55%) and Maharajganj (50%) (Table 41). The frequency of disease on root sample basis was higher (44.44%) in Gorakhpur proper than in Maharajganj (41.66%) and Gola Bazar (34.54%) (Table 41).

The intensity of the disease was moderate to very severe (3-5/3-5) in Gorakhpur proper; mild to severe (2-5/2-5) in Maharajganj and in Gola Bazar (Table 41).

Among the vegetables, highest incidence of the disease was found in pepper fields (80%) followed by cauliflower (66.66%) and eggplant (60%).

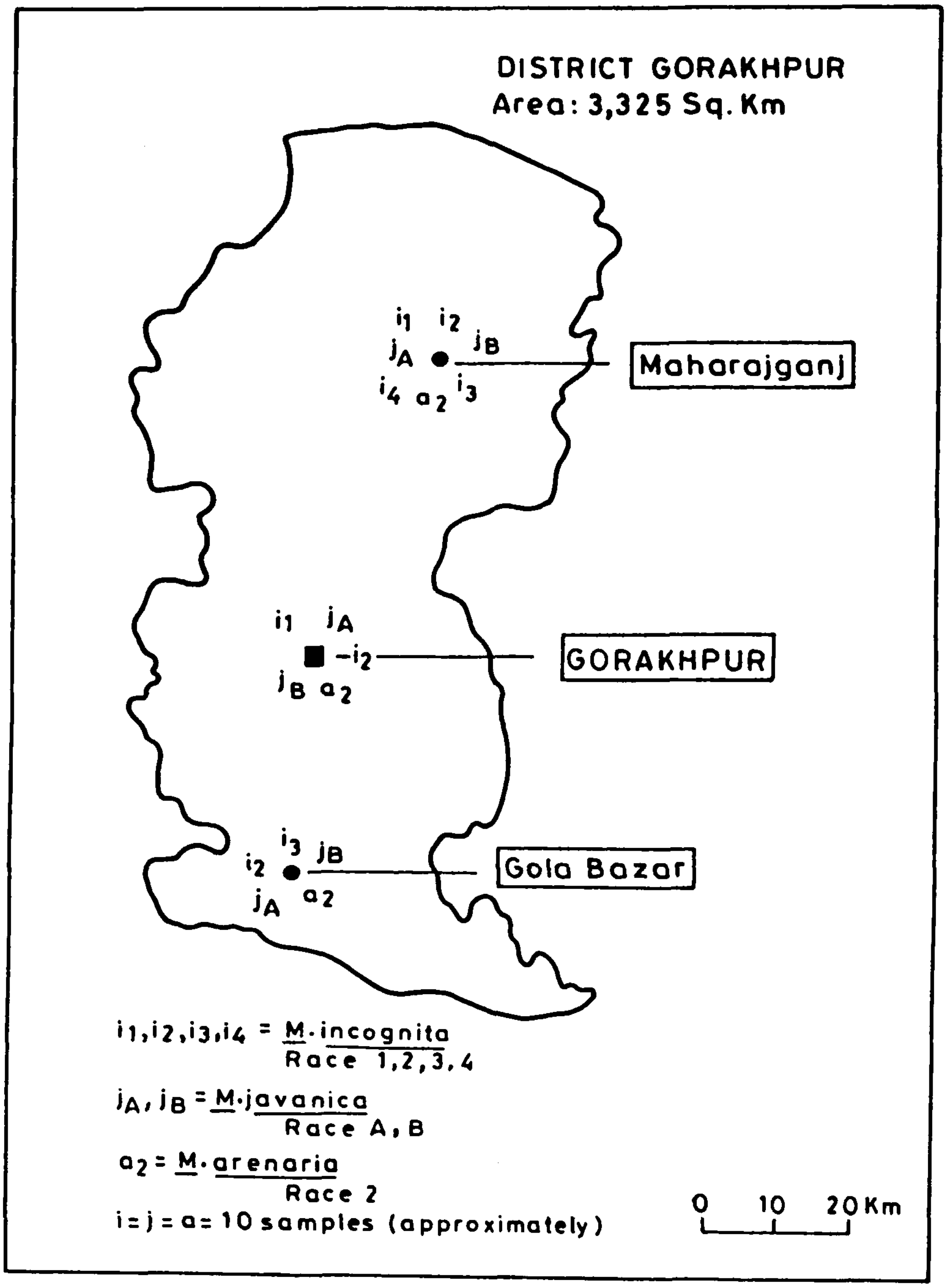

Fig. 10. Distribution of *Meloidogyne* species and their races in Gorakhpur district.

Table 41. Incidence and intensity of root-knot nematodes on vegetable crops in different localities of Gorakhpur district

Locality	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Gorakhpur proper	7	4	57.14	63	28	44.44	3-5/3-5
Maharajganj	8	4	50.00	60	25	41.66	2-5/1-5
Gola Bazar	9	5	55.55	55	19	34.54	2-5/2-5
Total	24	13	54.16	178	72	40.44	2-5/1-5

* GI = Gall index; EMI = Egg mass index.

Tomato, cucumber and cabbage fields showed 50% infestation with root-knot nematodes. Okra fields in the district were free from infestation (Table 42).

On root samples basis, frequency of the disease was highest on eggplant (72.50%) followed by tomato (53.20%). Lowest frequency was noticed on cauliflower roots (16.66%) (Table 42).

Intensity of discase on pepper and tomato was moderate to very severe, GI/EMI being 3-5/3-5. Intensity of the disease was severe to very severe (4-5/4-5) on eggplant and mild to very severe (2-5/2-5) on cauliflower, cabbage and cucumber (Table 42).

Identity of the species

Three species of root-knot nematodes viz. *M. incognita, M. javanica* and *M. arenaria* were recorded from the district (Fig. 10, Table 43). In single populations, *M. incognita* and *M. javanica* were found in Gorakhpur proper, *M. incognita* and *M. arenaria* in Maharajganj and *M. javanica* and *M. arenaria* in Gola Bazar. Mixed populations of *M. incognita* + *M. javanica* and *M. incognita* + *M. javanica* + *M. arenaria* were present in all the localities (Table 43).

Frequency of the species in single and mixed populations

In single populations, frequency of *M. incognita* (42.85%) was greater than *M. javanica* (25%) in Gorakhpur proper; of *M. incognita* (40%) than *M. arenaria* (4%) in Maharajganj and of *M. javanica* (42.10%) than *M. arenaria* (15.78%) in Gola Bazar.

Among the localities, highest frequency of *M. incognita* (54.54%) was observed in Gorakhpur proper and of *M. javanica* (53.33%) and *M. arenaria* (75%) in Gola Bazar as compared to other localities (Table 43).

Table 42. Incidence and intensity of root-knot nematodes on different vegetable crops in Gorakhpur district

Crop	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Pepper	5	4	80.00	45	17	37.77	3-5/3-5
Eggplant	5	3	60.00	40	29	72.50	4-5/4-5
Tomato	4	2	50.00	32	17	53.12	3-5/3-5
Okra	3	-	-	21	-	-	-
Cucumber	2	1	50.00	12	04	33.33	2-5/1-5
Cauliflower	3	2	66.66	18	03	16.66	2-5/2-5
Cabbage	2	1	50.00	10	02	20.00	2-5/2-5

* GI = Gall index; EMI = Egg mass index.

In Gorakhpur proper and Maharajganj, frequency of mixed infections of *M. incognita* + *M.javanica* + *M. arenaria* was greater than other combinations. In Gola Bazar, frequency of *M. incognita* + *M. javanica* (31.57%) was higher than *M. incognita* + *M. javanica* + *M. arenaria* (10.52%) combination (Table 43).

Among the localities, frequency of mixed populations of *M. incognita* + *M. javanica* (46.15%) was highest in Gola Bazar and *M. incognita* + *M. javanica* + *M. arenaria* (50.00%) in Maharajganj. *M. incognita* + *M. arenaria* and *M. javancia* + *M. arenaria* combinations were recorded only from Maharajganj and Gorakhpur proper, respectively. Consequently, their frequencies were 100% (Table 43).

Frequency of the species in total infected samples

In total root samples, frequency of *M. incognita* was greater than *M. javanica* and *M. arenaria* in Gorakhpur proper and Maharajganj. In Gola Bazar, frequency of *M. javanica* (84.21%) was greater than *M. incognita* (42.10%) and *M. arenaria* (26.31%) (Table 44).

Among the localities, frequencies of *M. incognita* (48%) and *M. arenaria* (45.45%) in Maharajganj and *M. javanica* (37.20%) in Gorakhpur proper and Gola Bazar were greater as compared to other localities (Table 44).

Identity and frequency of races

Races 1, 2, 3 and 4 of *M. incognita;* races A and B of *M. javanica* and race 2 of *M. arenaria* were recorded from the district (Fig. 10, Table 45). Races 1 and 2 of *M. incognita* were observed in Gorakhpur proper and their frequencies were 55.56% and 44.44%, respectively. Of the four races of *M. incognita,* frequency of race 1 was greater than other races in Maharajganj. In Gola Bazar, race 2 (62.50%)

Table 43. Frequency of occurrence of species (%) of the root-knot nematodes in single and mixed populations on vegetable crops in different localities of Gorakhpur district

Locality	Frequency of species						
	Single population			Mixed population			
	Mi	Mj	Ma	Mi+Mj	Mi+Ma	Mj+Ma	Mi+Mj+Ma
Gorakhpur	42.85*	25.00	-	7.14	-	10.71	14.28
proper	(54.54)**	(46.66)		(15.38)		(100.00)	(33.33)
Maharajganj	40.00	-	4.00	20.00	12.00	-	24.00
	(45.45)		(25.00)	(38.46)	(100.00)		(50.00)
Gola Bazar	-	42.10	15.78	31.57	-	-	10.52
		(53.33)	(75.00)	(46.15)			(16.66)

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

Table 44. Frequency of occurrence of the species (%) of root-knot nematodes in different localities of Gorakhpur district based on total infected root samples of vegetables

Locality	Total infected root samples	No. of root samples infected (Single +Mixed population)			Frequency of species in total infected samples		
		Mi	Mj	Ma	Mi	Mj	Ma
Gorakhpur proper	28	18	16	07	64.28* (36.00)**	57.14 (37.20)	25.00 (31.81)
Maharajganj	25	24	11	10	96.00 (48.00)	44.00 (25.58)	40.00 (45.45)
Gola Bazar	19	08	16	05	42.10 (16.00)	84.21 (37.20)	26.31 (22.72)

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

Table 45. Frequency of occurrence of races of *Meloidogyne incognita* (Mi), *Meloidogyne javanica* (Mj) and *Meloidogyne arenaria* (Ma) in different localities of Gorakhpur district

Locality	Species/ Races	Frequency (%) of the races of *Mi*				Frequency (%) of the races of *Mj*		Frequency (%) of the races of *Ma*	
		R_1	R_2	R_3	R_4	A	B	R_1	R_2
Gorakhpur	Mi_{R1}, Mi_{R2},	55.56*	44.44	-	-	68.75	31.25	-	100.00
proper	Mj_A, Mj_B, Ma_{R2},	(45.45)**	(40.00)			(35.48)	(41.67)		(31.82)
Maharajganj	Mi_{R1}, Mi_{R2}, Mi_{R3}, Mi_{R4},	50.00	29.17	8.33	12.50	72.73	27.27	-	100.00
	Mj_A, Mj_B, Ma_{R2},	(54.55)	(35.00)	(40.00)	(100.00)	(25.81)	(25.00)		(45.45)
Gola Bajar	Mi_{R2}, Mi_{R3},	-	62.50	37.50	-	75.00	25.00	-	100.00
	Mj_A, Mj_B, Ma_{R2},		(25.00)	(60.00)		(38.71)	(33.33)		(22.73)

* Values in rows represent frequency (%) of the races in the same locality.

** Values in parentheses in the columns of the races represent frequency (%) of the races in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

R_1 = race 1; R_2 = race 2; R_3 = race 3 and R_4 = race 4 of *M. incognita* or *M. arenaria.*

A = race A and B = race B of *M. javanica.*

was more frequent than race 3 (37.52%). Among the localities, frequency of race 1 (54.55%) was highest in Maharajganj; of race 2 (40%) in Gorakhpur proper and of race 3 (60%) in Gola Bazar. Frequency of race 4 was 100% as this was recorded only from Maharajganj (Table 45).

In *M. javanica* populations, race A was more frequent than race B in all the localities. Among the localities, frequency of race A (38.71%) was highest in Gola Bazar and race B (41.67%) in Gorakhpur proper (Table 45).

Race 2 of *M. arenaria* was recorded from all three localities. Its frequency was highest in Maharajganj (45.45%) as compared to in Gorakhpur proper (31.82%) and in Gola Bazar (22.73%) (Table 45).

DEORIA

Incidence and intensity of the disease

Deoria proper, Salimpur and Padrauna localities of Deoria districts were surveyed (Fig. 11). Root samples of vegetable crops were collected from all the localities. The incidence of the disease in vegetable fields was highest in Padrauna (55.55%) followed by Deoria proper (50%) and Salimpur (44.44%). The average incidence of the disease in the district was 50% (Table 46).

The incidence, on root sample basis, was also highest in Deoria proper (46%). In Salimpur and Padrauna per cent incidence of disease was 26.38% and 31.25%, respectively (Table 46).

The disease intensity were mild to very severe (2-5/2-5) in Deoria proper and Salimpur and very mild to severe (1-5/1-5) in Padrauna, based on GI/EMI ranges (Table 46).

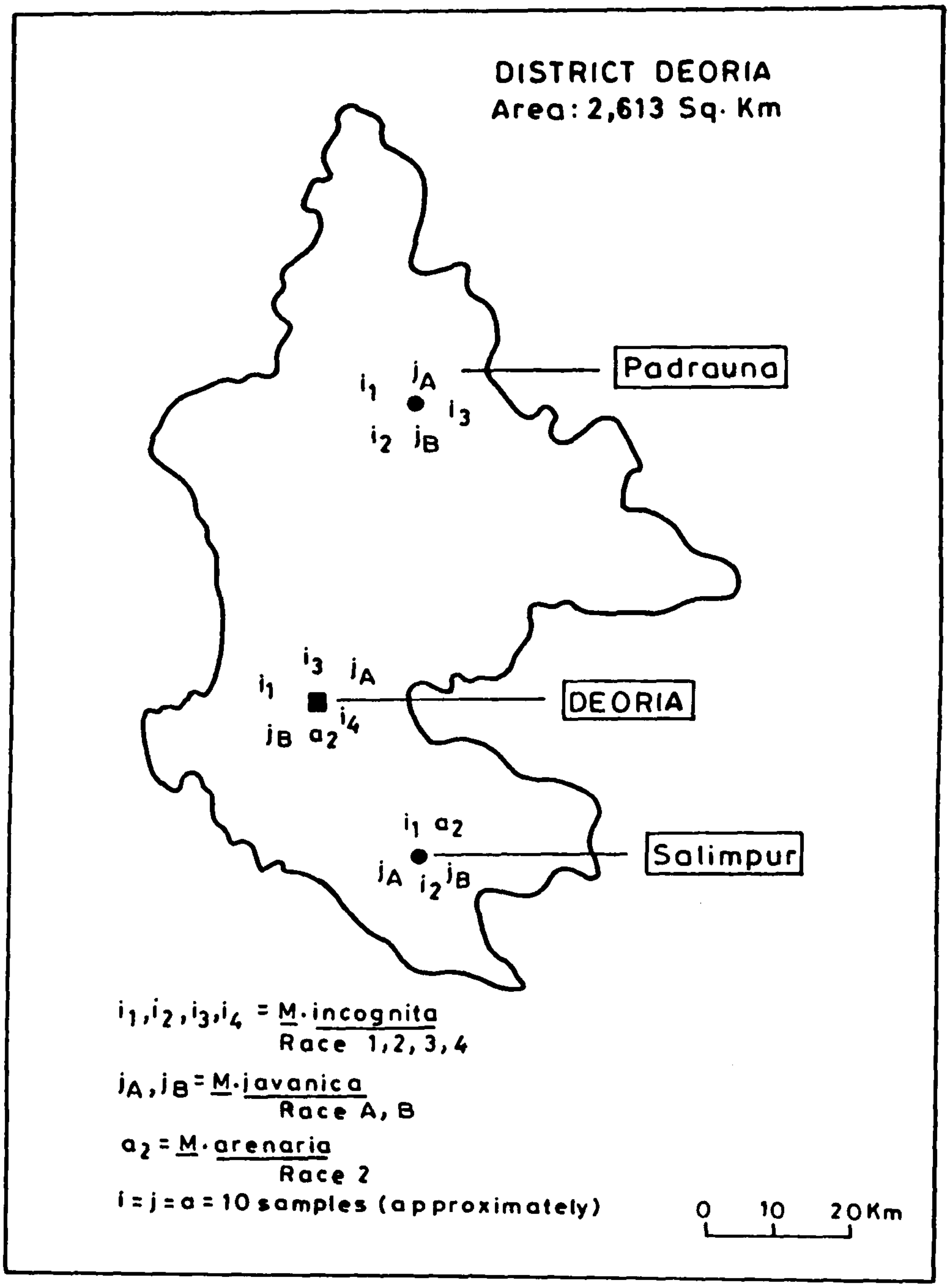

Fig. 11. Distribution of *Meloidogyne* species and their races in Deoria district.

Table 46. Incidence and intensity of root-knot nematodes on vegetable crops in different localities of Deoria district

Locality	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Deoria proper	10	5	50.00	50	23	46.00	2-5/2-5
Salimpur	9	4	44.44	72	19	26.38	2-5/2-5
Padrauna	9	5	55.55	64	20	31.25	1-5/1-5
Total	28	14	50.00	186	62	33.33	1-5/1-5

* GI = Gall index; EMI = Egg mass index.

Among the vegetable crops, highest incidence of the disease was found in eggplant fields followed by cauliflower, tomato and pepper fields. Lowest frequency (33.33%) was observed in okra, cucumber and cabbage fields (Table 47).

The incidence of disease on infected root samples was highest on eggplant (58.33%). On rest of the vegetables, incidence was below 50% (Table 47).

Moderate to very severe (3-5/3-5) intensity was observed on eggplant and very mild to severe (1-5/1-5) on cucumber and cabbage (Table 47).

Identity of the species

In the district, *M. incognita*, *M. javanica* and *M. arenaria* were found infesting the vegetable fields. They were present either in single or in mixed populations in the localities of the district (Fig. 11, Table 48).

Frequency of the species in single and mixed populations

The frequency of single population of *M. incognita* was greater than other species in all the localities (Table 48). Lowest frequency was found for *M. arenaria* (5.26%) populations in Salimpur locality. Among the localities, frequency of *M. incognita* (38.66%) was highest in Deoria proper and of *M. javanica* (62.50%) in Padrauna. In Salimpur, only *M. arenaria* was found, so its frequency was 100% (Table 48). Frequency of mixed populations of *M. incognita* + *M. javanica* was greater in all the localities than other combinations of the species, lowest being of *M. javanica* + *M. arenaria* combination. Among the localities, *M. incognita* + *M. javanica* (37.50%) showed highest frequency in Padrauna and *M. incognita* + *M. arenaria* in Deoria proper (57.14%). *M. javanica* + *M. arenaria* and of all the three species combinations were recorded only from Deoria proper and Salimpur, so their frequencies were 100% (Table 48).

Table 47. Incidence and intensity of root-knot nematodes on different vegetable crops in Deoria district

Crop	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Pepper	5	2	40.00	30	10	33.33	2-5/2-5
Eggplant	7	5	71.42	36	21	58.33	3-5/3-5
Tomato	4	2	50.00	28	09	32.14	2-5/2-5
Okra	3	1	33.33	18	06	33.33	2-5/2-5
Cucumber	3	1	33.33	23	07	30.43	1-5/1-5
Cauliflower	3	2	66.66	21	05	23.80	2-5/1-5
Cabbage	3	1	33.33	30	04	13.33	1-5/1-5

* GI = Gall index; EMI = Egg mass index.

Table 48. Frequency of occurrence of species (%) of the root-knot nematodes in single and mixed populations on vegetable crops in different localities of Deoria district

Locality	Frequency of species						
	Single population			Mixed population			
	Mi	Mj	Ma	Mi+Mj	Mi+Ma	Mj+Ma	Mi+Mj+Ma
Deoria proper	43.47*	13.04	-	21.73	17.39	4.34	-
	(38.46)**	(37.50)		(31.25)	(57.14)	(100.00)	
Salimpur	36.84	-	5.26	26.31	15.78	-	15.78
	(26.92)		(100.00)	(31.25)	(42.85)		(100.00)
Padrauna	45.00	25.00	-	30.00	-	-	-
	(34.61)	(62.50)		(37.50)			

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita*, Mj = *M. javanica;* Ma = *M. arenaria.*

Frequency of the species in total infected samples

When frequency of occurrence of the species in total infected root samples was analysed, it was found that *M. incognita* was more frequent than *M. javanica* and *M. arenaria* in all the localities. Frequency of *M. javanica* was greater than *M. arenaria* in all the localities (Table 49).

Among the localities, the frequency of *M. incognita* (48%) was highest in Salimpur, *M. javanica* (39.28%) in Padrauna and *M. arenaria* in Salimpur (45.45%) as compared to other localities.

Identity and frequency of races

All the four races of *M. incognita* (races 1, 2, 3 and 4); two races of *M. javanica* (races A and B) and race 2 of *M. arenaria* were observed in the district (Fig. 11, Table 50).

In Deoria proper, frequency of race 3 (42.11%) of *M. incognita* was greater in frequency than race 1 (36.84%). In Padrauna race 1 (53.33%) was more frequent than race 2 (26.67%) and race 3 (20%).

Among the localities, frequency of race 1 (38.10%) was highest in Padrauna; race 2 (75%) in Salimpur, race 3 (72.73%) in Deoria proper. Frequency of race 4 was 100% in Deoria proper as it was the only race present in the locality (Table 50).

In *M. javanica* populations, race A was more frequent than race B in all the localities (Table 50). When frequency was compared between the localities, race A (45%) showed highest frequency in Padrauna and race B in Deoria proper and Salimpur (37.50%) (Table 50).

In *M. arenaria* populations, only race 2 was present in the district. Therefore, its frequency was 100% in all the localities. Among the localities its frequency was highest in Salimpur (58.33%) and lowest in Deoria proper (41.67%) (Table 50).

Table 49. Frequency of occurrence of the species (%) of root-knot nematodes in different localities of Deoria district based on total infected root samples of vegetables

Locality	Total infected root samples	No. of root samples infected (Single +Mixed population)			Frequency of species in total infected samples		
		Mi	Mj	Ma	Mi	Mj	Ma
Deoria proper	23	19	09	05	82.60*	39.13	21.73
					(36.53)**	(32.14)	(41.66)
Salimpur	19	18	08	07	94.73	42.10	36.84
					(48.00)	(25.58)	(45.45)
Padrauna	20	15	11	-	75.00	55.00	-
					(28.84)	(39.28)	

* Values in rows represent frequency (%) of the species in the same locality.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria*.

Table 50. Frequency of occurrence of races of *Meloidogyne incognita* (Mi), *Meloidogyne javanica* (Mj) and *Meloidogyne arenaria* (Ma) in different localities of Deoria district

Locality	Species/ Races	Frequency (%) of the races of *Mi*				Frequency (%) of the races of *Mj*		Frequency (%) of the races of *Ma*	
		R_1	R_2	R_3	R_4	A	B	R_1	R_2
Deoria Proper	Mi_{R1}, Mi_{R3}, Mi_{R4},	36.84*	-	42.11	21.05	66.67	33.33	-	100.00
	Mj_A, Mj_B, Ma_{R2}	(33.33)**		(72.73)	(100.00)	(30.00)	(37.50)		(41.67)
Salimpur	Mi_{R1},Mi_{R2},	33.33	66.67	-	-	62.50	37.50	-	100.00
	Mj_A, Mj_B, Ma_{R2}	(28.57)	(75.00)			(25.00)	(37.50)		(58.33)
Padrauna	Ma_{R1}, Mi_{R2}, Mi_{R3},	53.33	26.67	20.00	-	81.82	18.18	-	-
	Mj_A, Mj_B, Ma_{R2}	(38.10)	(25.00)	(27.27)		(45.00)	(25.00)		

* Values in rows represent frequency (%) of the races in the same locality.

** Values in parentheses in the columns of the races represent frequency (%) of the races of in different localities.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria.*

R_1 = race 1; R_2 = race 2; R_3 = race 3 and R_4 = Race 4 of *M. incognita* or *M. arenaria.*

A = race A and B = race B of *M. javanica.*

Overall incidence and intensity of the disease

Overall incidence of root-knot disease on vegetables was assessed in the 9 districts of three diffrent regions of Uttar Pradesh i.e. Almora, Pauri Garhwal, Dehradun (Hilly region), Farrukhabad, Hardoi, Sitapur (Central region), Basti, Gorakhpur and Deoria (Eastern region) (Fig. 2). Incidence of the disease was highest in Farrukhabad district. About 58% fields were infested with root-knot nematodes. In the fields of other districts, the incidence of the disease ranged between 44% to 55.55%. The average incidence of the disease in the districts was 50.72%.

On the basis of root samples, the overall incidence was 36.11% . The highest incidence was found in Farrukhabad (41.34%) followed by Gorakhpur (40.44%) and Sitapur (40.27%). In rest of the districts it ranged from 28.97% to 39.50%, lowest being in Almora. In all the districts except Almora and Dehradun more than 30% root samples of vegetable crops were infected. GI/EMI ranged between 1-5/0-5 (Table 51).

Highest incidence of the disease was observed in eggplant (70%) fields followed by tomato(51.42%), pepper (47.50%), cauliflower (45.45%), cabbage (43.75%), okra (39.13%) and cucumber (33.33%) (Table 52).

Intensity of the disease on the basis of GI/EMI (1-5/0-5) showed a wide range of variations (Table 52). It varied from field to field, vegetable to vegetable or even from sample to sample. The intensity of the disease in different fields showed variations in each district. The intensity ranged between very mild to severe on mean GI/EMI basis.

On root sample basis, highest frequency was found on eggplant (59.79%) followed by tomato (40.63%). The frequency of occurrence of the disease was 33.81% on pepper, 27.70% on okra and 24.11% on cucumber roots. On cauliflower (14.11%) and cabbage (13.55%) roots, the frequency of the disease was relativily low (Table 52).

Table 51. Incidence and intensity of root-knot nematodes on vegetable crops in 9 district of 3 different regions of Uttar Pradesh

Region/District	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Hilly region							
Almora	22	10	45.45	176	51	28.97	2-5/2-5
Pauri Garhwal	25	11	44.00	154	57	37.01	2-5/2-5
Dehradun	23	11	47.82	204	57	29.94	2-5/2-5
Central region							
Farrukhabad	19	11	57.89	179	74	41.34	1-5/1-5
Hardoi	22	11	50.00	165	61	36.96	2-5/0-5
Sitapur	26	14	53.84	216	87	40.27	1-5/1-5
Eastern region							
Basti	18	10	55.55	162	64	39.50	1-5/1-5
Gorakhpur	24	13	54.16	178	72	40.44	2-5/1-5
Deoria	28	14	50.00	186	62	33.33	1-5/1-5
Total	207	105	50.72	1620	585	36.11	1-5/0-5

* GI = Gall index; EMI = Egg mass index.

Intensity of the disease on different vegetables in terms of GI/EMI varied. Variations in the intensity were noticed in different fields or on different root samples of the same crop (Table 52).

Identity of the species

All the four major species of *Meloidogyne* viz. *M. incognita*, *M. javanica*, *M. arenaria* and *M. hapla* were found to be present in the area surveyed. *M. incognita*, *M. javanica* and *M. arenaria* were encountered in all the districts. *M. hapla* was, however, found only in hilly districts, Almora, Pauri Garhwal and Dehradun (Table 53).

Frequency of the species in single population

M. incognita, *M. javanica* and *M. arenaria* were found in single populations in all the districts except *M. arenaria* which was not recorded in Dehradun and Basti districts. Single population of *M. hapla* was found in all the three hilly districts (Almora, Pauri Garhwal and Dehradun). When frequency of occurrence of species was analysed district-wise, frequency of *M. incognita* was more than other three species in all the districts except Sitapur where frequency of *M. javanica* was greater than other species (Table 53). When the frequency of occurrence of a species was compared among the 9 districts of the study area, it was observed that frequencies of *M. incognita* (48.29%) and *M. javanica* (18.27%) were highest in Farrukhabad than in the rest of the districts. *M. arenaria* (35.71%) was highest in Sitapur and *M. hapla* in Dehradun (43.75%) (Table 53).

The per cent occurrence of single population of the root-knot nematodes in 9 districts was 49.74% (Table 56). Of total 291 root samples infected with single populations of the root-knot nematodes, 164 contained *M. incognita*, 83 *M. javanica*, 28 *M. arenaria* and 16

Table 52. Incidence and intensity of root-knot nematodes on different vegetable crops in Uttar Pradesh

Crop	Incidence						Intensity
	No. of cultivation units			No. of root samples			GI/EMI*
	Surveyed	Infested	Frequency	Collected	Infected	Frequency	(Range)
Pepper	40	19	47.50	343	116	33.81	2-5/2-5
Eggplant	50	35	70.00	388	232	59.79	2-5/1-5
Tomato	35	18	51.42	283	115	40.63	2-5/2-5
Okra	21	07	33.33	148	41	27.70	2-5/1-5
Cucumber	23	09	39.13	170	41	24.11	2-5/1-5
Cauliflower	22	10	45.45	170	24	14.11	1-5/1-5
Cabbage	16	07	43.75	118	16	13.55	1-5/0-5
Total	207	105	50.72	1620	585	36.11	1-5/0-5

* GI = Gall index; EMI = Egg mass index.

M. hapla in single population. The per cent occurrence was 28.03, 14.19, 4.79 and 2.74 for *M. incognita, M. javanica, M. arenaria* and *M. hapla*, respectively (Table 56).

Frequency of the species in mixed populations

Mixed populations of 6 combinations of the *Meloidogyne* spp. were recorded from the study area (Table 53). *M. incognita* + *M. javanica* and *M. incognita* + *M. arenaria* combinations were present in all the districts. *M. incognita* + *M. hapla* and *M. arenaria* + *M. hapla* were found only in Almora, Pauri Garhwal and Dehradun districts. *M. incognita* which was found mixed with *M. javanica* in all the districts was also present in mixture with *M. arenaria* in all the districts except Farrukhabad (Table53). Frequency of occurrence of mixed populations of *M. incognita* and *M. javanica* was greater than other combinations in all the districts except Almora and Dehradun where frequencies of *M. incognita* + *M. hapla* was greater than other species combinations (Table 53). When frequency of mixed populations of different species was compared among the districts, frequencies of mixed populations of *M. incognita* + *M. javanica* (15.78) and *M. incognita* + *M. arenaria* (19.04) were found to be highest in Hardoi district. Frequencies of *M. incognita* + *M. hapla, M. javanica* + *M. arenaria, M. arenaria* + *M. hapla* and *M. incognita* + *M. javanica* + *M. arenaria* combinations were highest in Almora, Sitapur, Pauri Garhwal and Sitapur, respectively (Table 53).

The per cent occurrence of mixed populations of root-knot nematodes was 50.26 in the study area in contrast to 49.74 of single populations (Table 56). Out of 585 infected root samples, 294 showed mixed populations of various combinations of species. *M. incognita* + *M. javanica* combinations was most frequent, being 19.48%. The per cent

Table 53. Frequency of occurrence of species (%) of the root-knot nematodes in single and mixed populations on vegetable crops in 9 districts of Uttar Pradesh

Districts	Single population				Mixed population					
	Mi	Mj	Ma	Mh	Mi+Mj	Mi+Ma	Mi+Mh	Mj+Ma	Ma+Mh	Mi+Mj+Ma
Almora	19.60*	11.76	1.96	11.76	9.80	5.88	23.52	-	1.96	13.72
	(6.09)**	(7.22)	(3.57)	(37.50)	(4.38)	(7.14)	(41.37)		(9.09)	(12.06)
Pauri Garhwal	14.03	12.28	7.01	5.26	17.54	8.77	12.28	7.01	10.52	5.26
	(4.87)	(8.43)	(14.28)	(18.75)	(8.77)	(11.90)	(24.13)	(10.00)	(54.54)	(5.17)
Dehradun	21.05	14.03	-	12.28	14.03	1.75	17.54	-	7.01	12.28
	(7.31)	(9.63)		(43.75)	(7.01)	(2.38)	(34.48)		(36.36)	(12.06)
Farrukhabad	40.54	20.27	9.45	-	17.56	6.75	-	5.40	-	-
	(18.29)	(18.07)	(25.00)		(11.40)	(11.90)		(10.00)		
Hardoi	29.50	8.19	1.63	-	29.50	13.11	-	8.19	-	9.83
	(10.97)	(6.02)	(3.57)		(15.78)	(19.04)		(12.50)		(10.34)
Sitapur	14.94	16.09	11.49	-	19.54	5.74	-	13.79	-	18.39
	(7.92)	(16.86)	(35.71)		(14.91)	(11.90)		(30.00)		(27.58)
Basti	39.06	7.81	-	-	21.87	7.81	-	17.18	-	6.25
	(15.24)	(6.02)			(12.28)	(11.90)		(27.50)		(6.89)
Gorakhpur	30.55	20.83	5.55	-	18.05	4.16	-	4.16	-	16.66
	(13.41)	(18.07)	(14.28)		(11.40)	(7.14)		(7.50)		(20.68)
Deoria	41.93	12.90	1.61	-	25.80	11.29	-	1.61	-	4.83
	(15.85)	(9.63)	(3.57)		(14.03)	(16.66)		(2.50)		(5.17)

* Values in rows represent frequency (%) of the species in the same district.

** Values in parentheses in columns of all the species represent frequency (%) of the species in different districts.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria;* Mh = *M. hapla.*

occurrence for *M. incognita* + *M. arenaria* was 7.18; *M. incognita* + *M. hapla* 4.96; *M. javanica* + *M. arenaria* 6.84; *M. arenaria* + *M. hapla* 1.88 and *M. incognita* + *M. javanica* + *M. arenaria* 9.91 (Table 56).

Frequency of the species in total infected root samples

In total infected samples regardless of single or mixed populations, the species of *Meloidogyne* showed variations in their frequencies in different districts. *M. incognita, M. javanica* and *M. arenaria* were recorded from all the districts. *M. hapla* was found only from Almora, Pauri Garhwal and Dehradun districts. Frequency of *M. incognita* was greater than *M. javanica* and *M. arenaria* in all the districts except Sitapur. In Sitapur, frequency of *M. javanica* was greater than *M. incognita* and *M. arenaria.* Frequency of *M. hapla* was greater than *M. javanica* and *M. arenaria* in Almora but lower than *M. incognita.* In Dehradun its frequency was, however, greater than *M. arenaria.*

Among the districts, frequency of *M. incognita* was highest in Deoria closely followed by Sitapur (12.53%), Hardoi (12.28%), Gorakhpur (12.28%) and lowest being 8.10% in Pauri Garhwal. Frequency of *M. javanica* was highest in Sitapur (20.%) followed by Gorakhpur, Hardoi, Basti, Farrukhabad, Deoria, Pauri Garhwal, Dehradun and Almora in this order. Frequency of *M. arenaria* was also highest in Sitapur followed by Pauri Garhwal, Gorakhpur, Hardoi, Basti, Farrukhabad, Almora, Dehradun and Deoria (Table 54).

Out of 585 infected root samples, 407 root samples contained. *M. incognita,* 295 *M. javanica,* 179 *M. arenaria* and 56 *M. hapla* populations. The per cent occurrence for *M. incognita, M. javanica, M. arenaria* and *M. hapla* in total infected root samples irrespective of single

Table 54. Frequency of occurrence of species (%) of the root-knot nematodes in the district of Uttar Pradesh based on total infected root samples of vegetables

Region/District	Total infected root samples	No. of root samples infected (Single + Mixed population)				Frequency of species in total infected samples			
		Mi	Mj	Ma	Mh	Mi	Mj	Ma	Mh
Hilly region									
Almora	51	37	18	12	19	72.54* (9.09)**	35.29 (6.10)	23.52 (6.70)	37.25 (33.92)
Pauri Garhwal	57	33	24	22	16	57.89 (8.10)	42.10 (8.13)	38.59 (12.29)	28.07 (28.57)
Dehradun	57	38	23	12	21	66.66 (9.33)	40.35 (7.79)	21.05 (6.70)	36.84 (37.50)
Central region									
Farrukhabad	74	48	32	16	-	64.86 (11.79)	43.24 (10.84)	21.62 (8.93)	-
Hardoi	61	50	34	20	-	81.96 (12.28)	55.73 (11.52)	32.78 (11.17)	-
Sitapur	87	51	59	43	-	58.62 (12.53)	67.81 (20.00)	49.42 (24.02)	-
Eastern region									
Basti	64	48	34	20	-	75.00 (11.79)	53.12 (11.52)	31.25 (11.17)	
Gorakhpur	72	50	43	22	-	69.44 (12.28)	59.72 (14.58)	30.25 (12.29)	-
Deoria	62	52	28	12	-	83.87 (12.78)	45.16 (9.49)	19.35 (6.70)	

* Values in rows represent frequency (%) of the species in the same district.
** Values in parentheses in columns of all the species represent frequency (%) of the species in different districts.
Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria* and Mh = *M. hapla.*

or mixed populations of species, was 69.57, 50.43, 30.60 and 9.57, respectively (Table 57).

Identity and frequency of the races

Four races of *M. incognita* i.e races 1, 2, 3 and 4; two races of *M. javanica* races A and B and race 2 of *M. arenaria* were recorded from the area included in the study. Races 1, race 2 and race 4 of *M. incognita* were found in all the districts except Sitapur where race 4 was absent. Race 3 was also present in all the districts except the hilly districts, Almora, Pauri Garhwal and Dehradun. Frequency of race 1 of *M. incognita* was greater than other races in all the districts except Hardoi, where frequency of race 2 was equal to race 1 and frequency of race 3 was equal to race 4. Frequency of race 2 of *M. incognita* was greater than race 3 and race 4 in all the districts except Basti where race 3 was greater than race 2 and race 4.

Among the districts, race 1 of *M. incognita* was highest in Sitapur followed by Farrukhabad, Gorakhpur, Dehradun, Deoria, Pauri Garhwal, Almora, Hardoi and Basti in this order. Frequency of race 2 was highest in Gorakhpur, followed by Hardoi, Deoria, Dehradun, Sitapur, Farrukhabad, Almora, Pauri Garhwal and Basti districts. Frequency of race 3 was highest in Basti followed by Deoria, Sitapur, Hardoi, Farrukhabad and Gorakhpur. Frequency of race 4 was highest in Basti and Hardoi followed by Almora, Farrukhabad, Gorakhpur, Deoria, Pauri Garhwal and Dehradun in this order (Table 55).

Out of 407 root samples with *M. incognita* populations analysed, 183 roots were infected with race 1, 127 with race 2, 52 with race 3 and 45 with race 4. The per cent occurrence of race 1, race 2, race 3 and race 4 was thus 44.96, 31.20, 12.78 and 11.06, respectively. From

Table 55. Frequency of occurrence of races of *Meloidogyne incognita* (Mi), *Meloidogyne javanica* (Mj) and *Meloidogyne arenaria* (Ma) in different district of Uttar Pradesh

Region/District	Species/ Races	Frequency (%) of the races of Mi				Frequency (%) of the races of Mj		Frequency (%) of the races of Ma	
		R_1	R_2	R_3	R_4	A	B	R_1	R_2
Hilly region									
Almora	Mi_{R1}, Mi_{R2}, Mi_{R4}, Mj_A, Mj_B, Ma_{R2}	51.35* (1038)**	32.43 (9.44)	-	16.21 (13.33)	72.22 (6.28)	27.78 (5.68)	-	100.00 (6.70)
Pauri Garhwal	Mi_{R1}, Mi_{R2}, Mi_{R4}, Mj_A, Mj_B, Ma_{R2}	57.57 (10.38)	33.33 (8.66)	-	9.09 (6.66)	75.00 (8.70)	25.00 (6.82)	-	100.00 (12.29)
Dehradun	Mi_{R1}, Mi_{R2}, Mi_{R4}, Mj_A, Mj_B, Ma_{R2}	55.26 (11.47)	36.84 (11.02)	-	7.89 (6.66)	69.57 (7.73)	30.43 (7.95)	-	100.00 (6.70)
Central region									
Farrukhabad	Mi_{R1}, Mi_{R2}, Mi_{R3}, Mi_{R4}, Mj_A, Mj_B, Ma_{R2}	47.91 (12.56)	27.08 (10.23)	12.50 (11.53)	12.50 (13.33)	68.75 (10.63)	31.25 (11.36)	-	100.00 (8.93)
Hardoi	Mi_{R1}, Mi_{R2}, Mi_{R3}, Mi_{R4}, Mj_A, Mj_B, Ma_{R2}	32.00 (8.74)	32.00 (12.59)	18.00 (17.30)	18.00 (20.00)	67.65 (11.11)	32.35 (12.50)	-	100.00 (11.17)
Sitapur	Mi_{R1}, Mi_{R2}, Mi_{R3}, Mj_A, Mj_B, Ma_{R2}	52.94 (14.75)	27.45 (11.02)	19.60 (19.23)	-	67.80 (19.32)	32.20 (21.59)	-	100.00 (24.07)
Eastern region									
Basti	Mi_{R1}, Mi_{R2}, Mi_{R3}, Mi_{R4}, Mj_A, Mj_B, Ma_{R2}	31.25 (8.19)	22.91 (8.66)	27.08 (25.00)	18.75 (20.00)	70.59 (11.59)	29.41 (11.36)	-	100.00 (11.17)
Gorakhpur	Mi_{R1}, Mi_{R2}, Mi_{R3}, Mi_{R4}, Mj_A, Mj_B, Ma_{R2}	45.83 (12.02)	41.66 (15.74)	6.25 (5.76)	10.00 (11.11)	72.09 (14.98)	27.91 (13.64)	-	100.00 (12.29)
Deoria	Mi_{R1}, Mi_{R2}, Mi_{R3}, Mi_{R4}, Mj_A, Mj_B, Ma_{R2}	40.38 (11.47)	30.76 (12.59)	21.15 (21.15)	7.69 (8.88)	71.43 (9.66)	28.57 (9.09)	-	100.00 (6.70)

* Values in rows represent frequency (%) of the races in the same district.

** Values in parentheses in the columns of the races represent frequency (%) of the races in different districts.

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria* and Mh = *M. hapla.*

R_1 = race 1; R_2 = race 2; R_3 = race 3 and R_4 = race 4 of *M. incognita* or *M. arenaria.*

A = race A and B = race B of *M. javanica.*

Table 56. Per cent occurrence of root-knot nematodes in single and mixed populations in 9 districts of Uttar Pradesh

Population of *Meloidogyne* species	Total number of samples with infection	Total number of samples with single or mixed population	No. of samples with the species	Per cent occurrence
	585			
Single population		291		49.74
M. incognita			164	28.03
M. javanica			83	14.19
M. arenaria			28	4.79
M. hapla			16	2.74
Mixed population		294		50.26
Mi +Mj			114	19.48
Mi + Ma			42	7.18
Mi + Mh			29	4.96
Mj + Ma			40	6.84
Ma + Mh			11	1.88
Mi + Mj + Ma			58	9.91

Mi = *M. incognita;* Mj = *M. javanica;* Ma = *M. arenaria* and Mh = *M. hapla.*

Table 57. Percent occurrence of root-knot nematodes in total infected samples in 9 districts of Uttar Pradesh

Meloidogyne species	Total number of sampels infected with *Meloidogyne* species	Number of samples with the species	Per cent occurrence of the species
M. incognita	585	407	69.57
M. javanica		295	50.43
M. arenaria		179	30.60
M. hapla		56	9.57

Note: In calculation of per cent occurrence both single and mixed populations of species in the samples have been included.

Table 58. Percent occurrence of races of *Meloidogyne incognita*, *Meloidogyne javanica* and *Meloidogyne arenaria* in 9 districts of Uttar Pradesh

Race of *Meloidogyne*	Total number of root samples infected with *Meloidogyne* species	Number of samples with the race	Per cent occurrence of the race.
M. incognita	407		
Race 1		183	44.96
Race 2		127	31.20
Race 3		052	12.78
Race 4		045	11.06
M. javanica	295		
Race A		207	70.17
Race B		088	29.83
M. arenaria	179		
Race 1		Nil	Nil
Race 2		179	100.00

the results it appeared that race 1 was the most frequent race among *M. incognita* populations (Table 58).

In *M. javanica* populations, race A was more frequent than race B in all the districts. When frequency of a race was compared among the districts, both the races of *M. javanica* (races A and B) showed highest frequency in Sitapur (19.32% and 21.59%) and lowest in Almora (6.28% and 5.68% respectively) (Table 55). Out of 295 root samples with *M. javanica* populations analysed, 207 were infected with race A and 88 with race B. The per cent occurrence of race A and race B was thus 70.17% and 29.83%, respectively. Race A was thus more frequent as compared to race B in the area (Table 58).

Race 2 of *M. arenaria* was identified to be present in the districts of the area surveyed. All 179 root samples infected with *M. arenaria* and collected from all the 9 districts contained only race 2 (Table 58). Among the districts, its frequency was highest in Sitapur (24.02%) (Table 55).

DISCUSSION

Meloidogyne incognita, M. javanica, M. arenaria and *M. hapla* are called as major species of root-knot nematodes because of their great agricultural importance across the world. They attack an array of vegetables grown in various agro-climatic zones of the world (Sasser, 1980; Taylor *et al.*, 1982). The results of the present investigations showed relatively high incidence of root-knot disease in vegetable fields in the study areas, comprising of nine districts (Almora, Pauri Garhwal, Dehradun, Farrukhabad, Hardoi, Sitapur, Basti, Gorakhpur and Deoria) belonging to 3 regions of Uttar Pradesh covering an area of 41,225 Sq. Kms. Above 50% vegetable fields were infested as evident from the overall incidence of the disease. The disease incidence in the root samples was above 36% regardless of vegetable crop or locality. The root samples collected from the districts of the central region were highly infected followed by eastern and hilly districts. More than 40% root samples were infected in Farrukhabad, Hardoi and Gorakhpur districts. The disease incidence was lowest in Almora (29%) and Dehradun (30%) (Table 51). A great degree of variations in each district or locality was, however, found in the intensity of the disease. It ranged from very mild to very severe. The GI and EMI means were more than 3 in each district. The mean and range of GI and EMI indicated that vegetable crops in general may be suffering substantially as a high percentage of vegetable fields are infested with root-knot nematodes. Population density of the identified species and races and crop damages would gradually increase. These nematodes may be inflicting appreciable damages on almost all commonly grown vegetables of the area. Since the incidence of the disease was highest on eggplant (60%) roots, it has emerged most commonly infected crop of the area. It was followed by tomato (40%), pepper (34%), okra (28%) and cucumber (24%). The root galling and egg mass production were also high on these crops. Root galling and egg mass production, on the other hand, were low on cauliflower (14%) and cabbage(13%). Eggplant is the most affected crop of the area and liable to suffer heavy losses. Damages caused by these nematodes on other vegetable crops may also be substantial. Vegetables are considered as most preferred and congenial hosts of root-knot nematodes, particularly the four major species. Root-knot nematodes as major pathogens of vegetables and other crops under different climatic conditions (Franklin, 1979; Sasser, 1979; Lamberti, 1979). Franklin (1979) reviewed the damages in vegetable crops caused by the major species of root-knot nematodes in different countries of Europe and Pacific. In cool temperate climate, the damages are negligible as compared to tropics. But root-knot nematodes cause real loss to the farmers in cool climates because in isolated places like in sandy soils and in glasshouses crops may be completely lost. The cash value of the crop is also important determinant of the economic losses (Franklin, 1979). Economic losses caused by root-knot nematodes in subtropical and Mediterranean climates are also significant in agriculture. A number of vegetables and other crops suffer economic damages in the Greece, Yugoslavia, Turkey, Egypt, Algeria and other countries of Mediterranean region particularly by *M. incognita*. (Lamberti, 1979).

Crop losses are very large in tropics and the estimated per cent loss due to root-knot nematodes on vegetable crops range from 15-30%. Potential for damage caused by root-knot nematodes is ever present in the tropics (Sasser, 1979). According to Mai (1985) it is very difficult and sometimes impossible to grow important vegetables such as tomatoes in tropics and subtropics because of root-knot nematodes, particularly *M. incognita*. It is now well established that root-knot nematodes are relatively more important in tropical and sub-tropical climates of the world than temperate climates. According to some estimates, average losses in crops like common bean, cowpea, pumpkin, tomato, cucumber, eggplant, potatoes, carrot, okra, spinach, pepper amount 11-46% (Sasser, 1979).

In India, tropical and sub-tropical climatic conditions prevail almost throughout the country. The potential of root-knot nematodes in attacking crop plants and causing economical damages is, therefore apparently high. Several available reports on the crop damages, caused by root-knot nematodes particularly on vegetables indicate enormous significance of these parasites in the country (Khan, 1988, Haider, 1989; Khan and Khan, 1990a, Krishnappa, 1985; Reddy, 1981; Krishnappa *et al.* 1981). Krishnappa (1985) remarked that reports on the estimates of yield losses caused by root-knot on crop of economic importance are infrequent, vague and imprecise. Recently Khan and Khan (1993, 1996) reviewed various aspects of root-knot disease of crop plants in India and emphasized that the occurrence and distribution of species and races of root-knot nematodes must be determined by extensive survey work in the country. Due to lack of systematic studies on distribution of root-knot nematodes and losses caused by them in different parts of country in crop fields, their real importance is yet to be fully recognized. In the present study, some of these aspects have been considered. The findings of the study show high incidence and intensity of the disease on the major vegetable crops grown in the area of study. Almost a similar pattern of occurrence of root-knot disease was also observed in some district of western and eastern Uttar Pradesh by other workers (Khan *et al.*, 1984, 1993, 1994, Khan and Khan, 1985, 1990a, 1996). In this study, quantative loss estimates have not been determined, but productivity of the vegetable crops is liable to suffer greatly due to wide spread occurrence of root-knot disease and the level of infestations. Management programmes for this group of nematodes must account this fact. The species identity of root-knot nematodes revealed through the study indicates that all the 4 major species viz., *M. incognita, M. javanica, M. arenaria* and *M. hapla* are present in the area with a variable pattern of distribution. *M. incognita, M. javanica* and *M. arenaria* were present in all the districts included in the study (Table 8, 13, 18, 23, 28, 33, 38, 43, 48). *M. hapla* showed a limited distribution, being restricted to Almora, Pauri Garhwal and Dehradun districts (Table 8, 13, 18). In totality, *M. incognita* is most frequent species in the area as it was dominant in all the districts. *M. javanica* is also widely distributed species present in all the districts and is a second most common species. *M. arenaria* and *M. hapla* occupy third and fourth positions respectively in this respect. In total samples (regardless of single or mixed infection) collected from all the districts 70% root samples contained *M. incognita,* 50% *M. javanica,* and 31% *M. arenaria. M. hapla* was found only in 10% of the root samples (Table 57). Similar pattern of distribution and dominance of the species were also observed in other districts of Uttar Pradesh by Khan (1988); Khan and Khan (1990a, 1991a, 1993, 1996; and Haider 1989). The species of root-knot nematodes present in the districts according to their relative occurrence and dominance can be arranged in the following order: *M. incognita* > *M. javanica* > *M. arenaria* > *M. hapla.*

Variations in species contents of different localities in the districts were, however, found. Such differences in species content and their concentration in specific localities have great significance in crop cultivation in that particular locality in relation to the selection of crops or cultivars taking into account their susceptibility to a species or race. This information would be helpful for management or extension nematologists.

The species were found either singly or in mixed populations (Table 53). In single populations, *M. incognita* was most frequent followed by *M. javanica* and *M. arenaria* in the area. In single population, *M. hapla* was also frequent in some districts where it occurred. Mixed populations of the two species with various combinations as *M. incognita* + *M. javanica*, *M. incognita* + *M. arenaria*, *M. incognita* + *M. hapla*, *M. javanica* + *M. arenaria*, *M. arenaria* + *M. hapla* or of three species as *M. incognita* + *M. javanica* + *M. arenaria* were found in the districts. Single and mixed populations of the species were comparable in occurrence, though mixed populations had slight edge over single species populations (Table 56). Mixed populations of *M. incognita* + *M. javanica* was most frequent followed by mixed populations of *M. incognita* + *M. javanica* + *M. arenaria* (Table 56). Single and mixed populations of the species also frequently occur in other parts of the world (Taylor, 1987; Taylor *et al.*, 1982). Mixed populations of the two or more species were also observed in vegetable fields of western and eastern Uttar Pradesh (Khan and Khan, 1990a, 1996; Khan *et al.* 1993, 1994). However, frequency of single populations was greater than mixed populations in these studies.

M. incognita is most important species of root-knot nematodes on world-wide basis. A large portion of root-knot populations in the tropics consists of this species; *M. javanica* ranks second which is followed by *M. arenaria*. *M. hapla* is infrequent in tropics (Sasser, 1979, 1980). *M. incognita* is also most wide-spread root-knot nematodes in sub-tropical and Mediterranean climates. In such climates, *M. javanica* is second most common species. *M. arenaria* is also world-wide in distribution but its local occurrence is less frequent than *M. incognita* and *M. javanica*. *M. hapla* is also found in sub-tropical and Mediterraneans climates (Lamberti, 1979). The climatic condition of the area in the present study is considered as sub-tropical. Three districts (Almora, Pauri Garhwal and Dehradun) located in Himalayan tracts have cold climatic conditions.

Under the aegis of IMP population analysis of root-knot nematodes from 8 geographical regions showed that *M. incognita*, *M. javanica*, *M. arenaria* and *M. hapla* are major species as about 95% of the populations was represented by these four species. *M. incognita* and *M. javanica* were found widely distributed in tropical, sub-tropical and warm temperate climates of the world. *M. arenaria* was also found in such climates but it was relatively less frequent. All three of these occurred in areas with an average temperature of 36°C or lower in the warmest month. *M. hapla* was found in temperate climate (Taylor *et al.* 1982; Sasser, 1985).

In several countries of Asia, *M. incognita* and *M. javanica* were also equally dominant. (Tayler *et al.*, 1982). In the neighbouring countries of India (Pakistan, Sri Lanka, Napal, Bangladesh and Burma) *M. incognita* and *M. javanica* have been recorded (Choudhury, 1981; Myint, 1981; Hogger, 1981; Maqbool and Saeed 1981; Sivapalan, 1981). The occurrence and pattern of distribution and relative dominance of *Meloidogyne* spp. in the study area showed a similar pattern. *M. incognita* and *M. javanica* were dominant species of the area. *M. arenaria* was relatively less frequent and *M. hapla* was restricted to hilly districts. *M. hapla* prefers the areas with annual average temperature less than 15°C and at an elevation above 1000m (Eisenback, *et al.*, 1981; Sasser and Carter, 1985). The annual average temperature of Almora, Pauri Garhwal and Dehradun districts where it was found is 12.8, 13.2 and 11.7°C and elevation is 1968.50m, 1970.50m and 1967.40-3022.50m respectively above sea level, supporting the presence of *M. hapla* in these districts.

The occurrence of mixed populations of the species in the area particularly in the districts located in plains are of great significance for management programmes and strategies. Ecological requirements of *M. incognita, M. javanica* and *M. arenaria* are overlapping. They inhabit in areas with average annual temperature between 15-33°C (Sasser and Carter, 1985). Their occurrence in mixed populations is also common in other parts of the world (Taylor *et al.* 1982, Taylor, 1987).

The reports available from 22 states of India (IMP Region VIII) with regard to the distribution of root-knot nematodes show that all the four major species of *Meloidogyne* are present in one or the other state. *M. incognita* has been reported from all the states where from reports are available except Jammu and Kashmir (Table 2). *M. javanica* exists in the states of Bihar, Haryana, Himachal Pradesh, Kerala, Rajasthan, Tamil Nadu, Uttar Pradesh, West Bengal and Union territories of Delhi and *M. arenaria* from Bihar, Delhi, Tamil Nadu, Uttar Pradesh and West Bengal. *M. hapla* has been recorded from Himachal Pradesh, Tamil Nadu, Uttar Pradesh and West Bengal (Table 2) According to Khan (1988), Haider (1989), Khan and Khan (1984, 1991a, 1992) in Uttar Pradesh root-knot nematodes are fairly widely distributed, infesting a high percentage of vegetables fields. The present finding regarding the presence of *M. hapla* and dominance of other species in U.P. also confirms the observations of Khan and Khan (1989a) and Khan *et al.* (1993).

The well designated races of *M. incognita*, (races 1-4) and race 2 of *M. arenaria* occurred in the study area (Table 55). Race 1 and race 2 of *M. incognita* showed wide distribution, followed by race 3 and race 4. Race 3 was not so frequent as it showed restricted distribution. Absence of race 3 from hilly districts of Almora, Pauri Garhwal and Dehradun may be due to the low temperature conditions prevailing in the districts which may not be favourable for it. In other parts of the world, race 3 and race 4 are also comparatively less frequent than races 1 and 2. All the four races of *M. incognita* have been identified in only few countries of the world. These races observed in Puerto Rico, Peru, Brazil, Ghana and Egypt (Taylor *et al.*, 1982). Race 1 constituted 72% and was recorded in all the countries of the IMP region except Chile, Liberia and Portugal. Race 2 is also common in many countries of IMP regions except in countries of region V (East Africa). In this region, race identification has been not undertaken except in Zimbabwe. Race 3 and race 4 are more or less equally frequent but are less common than race 1 and 2 in the world.

Possibility of greater variations in *M. incognita* populations exists in India as climatic conditions and cropping patterns are variable in different agro-climatic zones of the country. Concerted efforts for identification of races in root-knot nematode populations of the states in India is meagre. Race differentiation studies for *M. incognita* populations have been undertaken only in 9 states though the species is reported from 22 states. Occurrence of race 1 in Andhra Pradesh, Madhya Pradesh and Tamil Nadu (Krishnappa, 1982), races 1 and 2 in Bihar (Haider *et al.*, 1988) and Orissa (Routray and Das, 1982) and races 1-3 in Karnataka (Krishnappa, 1982; Krishnappa and Setty, 1983) has been reported. Uttar Pradesh and Haryana are the only states in the country wherein all the four races have been identified (Khan, 1988; Khan and Khan, 1991a, Bajaj *et al.*, 1986, Raja and Gill, 1982; Khan *et al.*, 1988). The present study also confirms the findings of above regarding the occurrence and dominance of races of *M. incognita* in Uttar Pradesh.

Meloidogyne javanica is also a common and important root-knot nematode species. It has a wide host range and is considered a major agricultural pest (Sasser *et al.*, 1983). The species, however, is generally regarded as non-pathogenic on pepper. Pepper cv. California Wonder is used as host differential for identification of this species in North Carolina host differential tests. Pathogenic variability is found among the different populations of the single plant nematode species. Despite this belief that pepper is not infected by *M. javanica*, there are several reports of *M. javanica* infections on pepper in many parts of the world (Jain *et al.*, 1983; Khan, 1988; Stephan, 1988; Rammah and Hirschmann, 1990; Walia and Gupta, 1986; Khan and Khan, 1991b; Eisenback and Triantaphyllou, 1991). Khan (1988) and Khan and Khan (1991a, 1996) during the surveys of vegetable fields in Uttar Pradesh found pepper infected with *M. javanica*. From Iraq, a similar report was made by Stephan (1988). In a comprehensive study, Rammah and Hirschmann (1990) made a comparative study of morphological characters of different populations of *M. javanica,* collected from the USA, Morocco and Egypt. No major morphological differences were found but the populations differed in their pathogenicity on pepper and peanut. One group of populations failed to infect pepper, other group was pathogenic on peanut and the third group was non-infective on both pepper and peanut. Possible existance of host races in *M. javanica* populations from different geographical areas was, thus, demonstrated. According to Eisenback and Triantaphyllou (1991) host races in *M. javanica* have not been recognized. However, some populations of *M. javanica* infect and reproduce on pepper but rarely on peanut. These populations informally referred then to as "pepper race" and "peanut race" of *M. javanica* by them.

Similar situation has emerged from the present study. *M. javanica* populations differed in their pathogenicity on two cultivars of pepper namely resistant cv. California Wonder (Taylor and Sasser, 1978) and susceptible cv. Suryamukhi Green (Khan and Khan, 1991b). One group of populations were non-infective on California Wonder but infected Suryamukhi Green while other group of populations were infective on both. Suryamukhi Green was infected by all populations. These two groups of populations are tentatively designated as 'race A' and 'race B'. Race A was found to be more frequent than race B in all the districts during the survey, with 70% and 30% overall frequency (Tables 10, 15, 20, 25, 30, 35, 40, 45, 50, 58). In artificial inoculation test Khan and Khan (1991b) showed that of fourteen cultivars of pepper most of them were rated as immune or resistant but a few as hypersusceptible or susceptible to this species. The study indicated towards two possibilities, first related to pathogenic variability in *M. javanica* populations and second to the variations in susceptibility of cultivars to a single populations of *M. javanica*. The present study also indicates both possibilities. A large number of populations of *M. javanica* should be evaluated in order to differentiate host races among its population as it is a second most common and wide-spread species of root-knot nematodes of the world. This information may be useful in developing cropping system strategies and in development of species or race-specific resistant crop varieties. Consequently, crop production strategies aimed at management of these races should have broad geographical utility.

Of two races known in *M. arenaria* only race 2 was found in the study area. It was present in all the districts (Tables 10, 15, 20, 25, 30, 35, 40, 45, 50). Highest frequency was observed in Sitapur followed by Pauri Garhwal, Hardoi and Basti, Farrukhabad, Almora, Dehradun and Deoria. A perusal of literature shows that race 2 is more common than race 1 in the world. Race 1 which infects, peanut occurs in Virginia, North Carolina, Georegia, Florida, Alabama and Texas in USA and is popularly known as peanut root-knot nematode (Sasser, 1980). *M. arenaria* population examined in different countries of the IMP regions, contained only race 2 with exception of Egypt and Morocco. In Egypt, race 1 alone and in Morocco both the races of *M. arenaria* were observed (Ibrahim, 1982, 1985). IMP data shows that about 84% *M. arenaria* populations belonged to race 2 and only 16% to race 1 (Taylor *et al.*, 1982). Race 2 is apparently widely distributed and may be constituting the larger portion of *M. arenaria* populations in India.

SUMMARY

Objective of the study presented in the section I of the thesis was to assess the incidence and intensity of root-knot disease and to establish the identity of species and races of root-knot nematodes infesting vegetable fields in order to understand their pattern of distribution in Uttar Pradesh. Nine districts from three regions namely Farrukhabad, Hardoi, Sitapur (Central region); Basti, Gorakhpur, Deoria (Eastern region); Almora, Pauri Garhwal and Dehradun (Hilly region) were selected for the study. Root samples of pepper, eggplant, tomato, okra, cucumber, cauliflower and cabbage were collected from different localities of the districts.

It emerged from the data that overall incidence of the disease on the vegetable crops was relatively high in the area. In all the 9 districts more than 50% of the fields surveyed were infested with root-knot nematodes and more than 36% root samples of the vegetable crops contained root-knot nematode infection. The incidence of the disease in vegetable fields was highest in Farrukhabad district (57.89%) and lowest in Pauri Garhwal (44%). Frequency of the disease on root sample was also highest in Farrukhabad (41.34%) closely followed by Gorakhpur (40.44%). The lowest incidence (28.97%) of the disease on root samples was recorded from Almora district.

On the basis of root samples, the incidence of disease was highest on eggplant (59.79%) followed by tomato (40.63%), pepper (33.81%), okra (27.70%), cucumber (24.11%), cauliflower (14.11%) and cabbage (13.55%) in this order.

Intensity of the disease in different localities of the districts and on different vegetable crops showed wide variations. It varied from field to field, vegetable to vegetable or even from sample to sample. The intensity

of the disease in different fields showed variations in each district. It ranged between very mild to severe/very mild to severe on GI/EMI respectively.

Meloidogyne incognita, *M. javanica*, *M. arenaria* and *M. hapla* were identified to be present in the area. *M. incognita*, *M. javanica* and *M. arenaria* were present in all the districts. *M. hapla* was restricted to the hilly districts. *M. incognita* was dominant species, occurring in all the districts of the study area. *M. javanica* was second most common and frequent species followed by *M. arenaria*. *M. hapla* was least frequent, and restricted in distribution. The species were found either singly or in mixed populations. In single populations *M. incognita* was also most frequent species in the area followed by *M. javanica* and *M. arenaria*. Mixed populations of two species viz., *M. incognita* + *M. javanica*, *M. incognita* + *M. arenaria*, *M. incognita* + *M. hapla*, *M. javanica* + *M. arenaria*, *M. arenaria* + *M. hapla*, or three species (*M. incognita* + *M. javanica* + *M. arenaria*) were found. The frequency of occurrence of the species in single species populations was slightly lower than mixed populations of the species. Mixed populations of *M. incognita* + *M. javanica* was most frequent followed by mixed populations of *M. incognita* + *M. arenaria*, *M. incognita* and *M. javanica* + *M. arenaria*.

Races 1-4 of *M. incognita;* race A and B of *M. javanica* and race 2 of *M. arenaria* were identified in the populations of the respective species in the area. Races 1, 2 and 4 of *M. incognita* were present in all the districts. Race 3 of *M. incognita* was absent from the hilly districts (Almora, Pauri Garhwal and Dehradun). Race 1 of *M. incognita* was most frequent followed by race 2. Races 3 and 4 were relatively less frequent. Race A and race B of *M. javanica* were present in all the districts. Race A of *M. javanica* was more frequent than race B in all the districts.

Race 2 was found invariably in all *M. arenaria* populations in all the districts. Race 1 of *M. arenaria* was not encountered in the area.

SECTION - II

Screening Studies

LITERATURE REVIEW

Reports available in literature on screening of cultivars of vegetable crops against root-knot nematodes, show that a very few cultivars of some of the vegetable crops have shown a varying degree of resistance against one or other species of the major root-knot nematodes and their races.

1. Pepper

Some cultivars of pepper (*Capsicum annuum*) have shown resistance to the root-knot nematodes. Early California Wonder cultivar of pepper was reported to be moderately resistant to *M. javanica* and Ruby King as resistant to *M. arenaria* while Ookview Wonder was found to be resistant to *M. javanica* and *M. arenaria* (Hare, 1956). Two cultivars 505 B Mexico and Santanka XS were also found to be resistant to *M. javanica, M. incognita* and *M. arenaria* (Hare, 1957); World Beater cultivar of pepper was designated as resistant to *M. incognita* and highly resistant to *M. javanica* (Sasser, 1954; Palo and Calinga, 1969). Bontoc Sweet Long and Dingras Rainy Season were found resistant to *M. incognita* (Palo and Calinga, 1969). California Wonder has been listed as resistant to *M. javanica* (Taylor and Sasser, 1978). All the 20 varieties of pepper tested against *M. incognita* by Reyes and Villanueva (1981) were rated resistant. Abu-Gharbieh (1982) screened four varieties of pepper and six of sweet pepper aganist *M. javanica* and *M. incognita*. All the varieties were rated resistant to the *M. javanica* and susceptible to *M. incognita* except California Yolo Wonder of sweet pepper which was resistant to both species. Chilli varieties Pusa Jwala, 579 and CAP 63 were reported to be resistant to *M. javanica* by Jain *et al.* (1983). Recently Khan and Khan (1991b, 1993) screened 14 cultivars of pepper against the four races of *M. incognita,* race 2 of *M. arenaria* and *M. javanica*. Several cultivars showed resistance against these nematodes.

Some cultivars showed race-specific resistance to *M. incognita*. Pusa Jwala and Jwala were resistant to all the species and races of the root-knot nematodes.

2. Eggplant

A number of cultivars of eggplant have been screened for their response to root-knot nematodes. A cultivar of eggplant, namely Black Beauty was found to be moderately resistant to *M. incognita* (Sasser, 1954; Birat, 1966; Alam *et al.*, 1974). Birat (1966) found Bhanta resistant and Muktakeshi and Round Red moderately resistant to *M. javanica*. Cultivars like Coolie and Mathis B were reported as resistant to *M. javanica* (Mathur *et al.*, 1971), Meyer's Market resistant to *M. incognita* (Calinga and Palo, 1972), Giant of Banaras and Gola moderately resistant to *M. incognita* (Alam *et al.*, 1974) and Vijaya resistant to *M. incognita* (Yadav *et al.*, 1975). Verma (1977) found all the cultivars of eggplant he tested, susceptible to *M. incognita*. However, some cultivars like Mysore Green and Pusa Purple Long Black were tolerant. Valdez (1981) screened eggplant selections for resistance to *M. incognita* and *M. javanica*. None of the 16 selections was rated as resistant to either test nematode, except Dingran Long Purple, La Granja Long Purple and Florida Market which showed moderate resistance to both nematode species. Similarly, Reyes and Villanueva (1981) screened seven varieties of eggplant against *M. incognita* of which three namely, Numaro Long, Dumaguete Long Purple and Annamali Brinjal, were rated resistant. Abu-Gharbieh (1982) screened six varieties of eggplant against *M. incognita* and *M. javanica*. None was rated resistant. Mysore Green, BR-112, America Big Round, Arkasheel, R-34, Sonepat Selection of eggplant were found to be moderately resistant to *M. javanica* by Jain *et al.* (1983). Reddy *et al.* (1986) evaluated 31 brinjal lines of diverse origins against *M. incognita*. Lines Maroo Marvel and Brinjal BR 112 were resistant to the species. Khan and Khan (1990, 1993) screened 19 cultivars of brinjal against the four races of *M. incognita, M. arenaria* (race 2) and *M. javanica*. None was rated resistant to either of the test nematodes.

3. Tomato

In tomato, some cultivars have shown resistance to root-knot nematodes. Malo (1964) found tomato cvs. Florida, Hawaian Cross Kola-C, Marbein Canner, Marbein Early, Marbein Midseason, Marbein Monarch resistant to *M. javanica* (Lal and Hameed, 1969). Zginailo (1970) screened some cultivars of tomato and found that All Round and Eurocross were resistant to *M. incognita*. Cultivars Atkinson and Manalucie were found to be resistant to *M. incognita, M. javanica* and *M. arenaria* by Singh and Chaudhary (1973). Sikora *et al.* (1973) screened certain cultivars of tomato for their resistance to *M. javanica* in India. Healani, Kalohi, Anahu, Hawaii 7526, Atkinson, Nematex, Y-207 and Y-240 showed no visible root galling, whereas VFN-8 and VFN-368 cultivars were heavily galled.

Krnjaic *et. al.* (1975) observed response of 42 tomato cultivars grown in an hydroponic substrate heavily infested with *M. incognita*. Pinta was free from galls but the galling was high on Azes Moira, B 67, R12 and R52. A cultivars of tomato Rossol was found to be resistant to *M. incognita* and *M. javanica* (Fassuliotis, 1976; Netscher, 1976). Patel *et al.* (1976) found Nematex and S-120 varieties of tomato resistant against *M. incognita* and *M. javanica*. Verma (1978) studied nine cultivars of tomato and found certain degree of resistance in Pusa Ruby and Kech Ruth against *M. incognita*. Abu-Gharbieh (1978) screened over 100 tomato cultivars under glasshouse conditions for resistance to *M. incognita* and *M. javanica*. Fourteen cultivars exhibited a good level of resistance to one or both species. Stephan (1979) reported that out of 71 cultivars of tomato tested, only 3 cultivars i.e. VFN-8, Rossol and Marmer were resistant against *M. javanica*. Kewalo, Healani and Druma were found to be resistant when 41 cultivars of tomato were screened against *M. incognita* by Sontirat (1981). Hemeng (1982) found only one line (AT-70/24) resistant in 17 cultivars of tomato to *M. incognita* and *M. javanica*. Yassin and Zeidan (1982) screened six varieties of tomato against *M. javanica*. Of the six varieties, five viz., Nemarid, Healani, Kalohi, Royal Chico and VFN-8 were found to be immune. Ibrahim (1982) tested eight cultivars to population of *M. incognita* (race 1 and race 3), *M. javanica* and *M. arenaria* race 1. None was found resistant. Dabaj and Khan (1982) screened 10 cultivars of tomato against *M. javanica* in Libya. Only one cultivar Tobol No. 748 F1 RS showed resistance. Lamberti *et al.* (1983) screened six tomato cultivars against local populations of *M. arenaria* and *M. javanica* in Sri Lanka. They found one cultivar (Katugstota) susceptible and five cultivars (Brech, Bush, Piersol, Rossol and VFN) resistant. Jain *et al.* (1983) found tomato varieties, Bangalore and SL-120 resistant to *M. javanica*. Narayana and Reddy (1983) found a tomato variety, NTDR-1 resistant to 10 isolates of *M. incognita* and susceptible to 4 isolates of *M. javanica*. Mahajan and Mangat (1984) screened 34 varieties of tomato against mixed population of *M. incognita* and *M. javanica*. Out of the varieties tested Bigest, Bonus, Contess, Better, Boy, Monte, Carlo, Beefmaster, VFN-360, Peirnita, Motabo, Motella, Hessolini, CI 3279, CI 3104 and CI B110 showed a varying degree of resistance. Rajkumar and Krishnappa (1984) found that cultivars like Pelican, Rossol, Ronita, VFN-8, Karnataka hybrid and A-1-1-2 were resistant to races 1, 2 and 3 of *M. incognita*. Raut (1986) while screening 10 tomato cultivars against *M. incognita* found only one cultivars (EC 118277) resistant to the species. Sasser *et al.* (1987) listed 25 accessions of tomato tested against the four major species and their races at the Asian Vegetable Research and Development Center (AVRDC), Taiwan. None showed resistance to *M. hapla*. Accessions, Roma -VC 8-1-2-1, CI-106-5-1-0, Kewalo L274, RV 12-L4109, RV 29-L 4126 and Atkinson-L313 were resistant to *M. incognita* races 1, 2, 3, 4; *M. arenaria* races 1, 2, and *M. javanica*. Khan and Khan (1991c, 1993) evaluated 36 accessions (cultigens) of tomato to all the four races (1, 2, 3, 4) of *M. incognita*, race 2 of *M. arenaria* and *M. javanica*. Several cultivars showed resistance. Resistance was also race-specific for *M. incognita* race populations. Ten accessions, Pusa - 120, Calmart VFN, Punjab 6 NR-7, EC 173898 (72 T6), EC 173897 (Calmart), EC 173896 (Kewalo) CLN 36 3BC, F_2 - 167-1-0, CLN 363 BC_1 F_2 -190-1-0, CLN 363 BC_1 F_2-344-0-0 and CLN299 BC1 F2-4-1-4-1-1-0 were immune to all the test nematodes and VFN-Bush and VFN - 8 were resistant.

4. Okra

In okra, Clemson Spineless has been found highly resistant to *M. hapla* and moderately resistant to *M. arenaria* (Sasser, 1954). Long Green Smooth was found to be resistant to *M. javanica* (Birat, 1966). Alam *et al.* (1974) found all the seven varieties of okra, included in their test susceptible to *M. incognita*. Rao and Singh (1977) screened 34 varieties of okra. None of the varieties tested was rated resistant. Cultivars IC-9273. IC-18960 were found to be resistant to *M. javanica* by Jain *et al.* (1983). Thakar and Patel (1985) tested seven varieties of okra to mixed population of *M. incognita* and *M. javanica*. All the tested varieties exhibited suceptibility. Out of ten varieties of okra tested against races (1, 2, 3, 4) of *M. incognita*, race 2 of *M. arenaria* and *M. javanica* by Khan and Khan (1989b), none was rated resistant.

5. Cucumber

Cucurbits which are used as vegetables or as ripe fruits have been screened to find resistance against root-knot nematodes. Winstead and Sasser (1956) screened 50 cucumber varieties and reported all of them to be susceptible to *M. incognita*. Mathur *et al.* (1971) screened some varieties of muskmelon against *M. incognita* but did not record any variety as resistant to the nematode. Abu-Gharbieh (1982) screened some cultivars of cucurbits against *M. javanica* and *M. incognita.* Of the 18 cucumber, 16 sweetmelon, five squash, seven watermelon varieties tested, only 3 i.e. Top Kapi and Dima F1 of squash were rated resistant to *M. javanica* and Crimson Sweet of watermelon to both the species. Rayes and Villanueva (1981) examined 5 varieties of cucumber for their resistance against *M. incognita.* Ashly and SMR-58 varieties were rated resistant. Jain *et al.* (1983) found muskmelon var. S-445 highly resistant to *M. javanica.* Ten varieties of watermelon and muskmelon were screened against *M. incognita* by Sharma *et al.* (1986) but none showed resistance. Dareker *et al.* (1988) screened 39 varieties of cucumber against race 3 of *M. incognita.* None of the varieties tested was found to be resistant except Gy - 5937-587 which was rated as moderately resistant. Khan and Khan (1989) screened nine varieties of cucumber against *M. javanica* and all the 4 races of *M. incognita.* Only one cultivar Improved Long Green was found resistant to *M. javanica.*

6. Cauliflower

Khan and Khan (1991d, 1993) evaluated 37 cultivars of cauliflower for their resistance against *M. javanica*, four races of *M. incognita* and race 2 of *M. arenaria* in green house pots. Most cultivars were susceptible to both species but some showed race-specific resistance. A single cultivar, Dania was immune to *M. javanica* and to all races of *M. incognita* and resistant to *M. arenaria* race 2.

7. Cabbage

Rayes and Villanueva (1981) screened 3 varieties of cabbage and 10 of lettuce against *M. incognita*. The cabbage varieties Leo 80 and K.K. were rated resistant. All of the lettuce varieties were found to be susceptible. Forty varieties of lettuce were tested against *M. hapla, M. incognita* and *M. javanica* for their resistance but none was rated resistant (Nishizawa, 1981). Five accessions or lines of cabbage obtained from AVRDC, were evaluated and no resistance was found to any of the four major species of *Meloidogyne* or to any of the their respective host races (Sasser *et al.*, 1987). Recently Khan and Khan (1990b) tested 23 varieties of cabbage to *M. javanica* and races of *M. incognita*. Four cultivars, American Special Ball Head, Red Drumhead, Glory of Enkhuizen and Sutton's Eclipse Drumhead showed resistance to the test nematodes. The other cultivars showed variable and race specific reactions.

From the very begining several attempts have been made in past to evaluate the cultivars of vegetable crops for their resistance against root-knot nematodes especially *M. incognita, M. javanica* and *M. arenaria* and some of cultivars have shown resistance too. But the inoculum levels and parameters or scales for measuring the resistance of the cultivars varied and consequently the degree or resistance of the cultivars assigned to cultivars were different in different studies. However, in past, races were not identified in root-knot nematodes.

Now in view of the existence of four well established races in *M. incognita* and two races in *M. arenaria* and *M. chitwoodi* and some indications of races in *M. javanica,* re-evalutions of the cultivars of vegetables for their resistance against the races of root-knot nematodes is greatly needed. At the same time in such re-evaluations standardized inoculum levels and parameters as suggested by Sasser *et al.* (1984) should be used. For a standard evaluation of plant response to root-knot nematodes, two parameters are measured: nematode reproduction; and plant damage caused by the nematode (Canto-Saenz, 1983). Nematode reproduction is determined by measuring the reproductive capability of nematode by using Oostenbrink (1966) formula: R=Pf/Pi. Plant damage is determined by counting the galls on roots and determining gall index (GI) by using 0-5 scale of Taylor and Sasser (1978).

Therefore, in present study, cultivars of seven vegetable crops have been screened for their resistance against the four races of *M. incognita* and two races of *M. javanica* in artificial inoculations and standard host suitability designations have been assigned following the method suggested by Sasser *et al.* (1984).

MATERIALS AND METHODS

Response of vegetable cultivars to root-knot nematodes

Commercial cultivars of pepper (*Capsicum annuum* L.), eggplant (*Solanum melongena* L.), tomato (*Lycopersicon esculentum* Mill.), okra (*Abelmoschus esculentus* L.) (Moen.), cucumber (*Cucumis sativus* L.), cauliflower (*Brassica oleracea* L. var. *botrytis*) and cabbage (*Brassica oleracea* L. *var capitata*) were screened for their degree of resistance in glasshouse against races 1, 2, 3 and 4 of *M. incognita* and races A and B of *M. javanica*. *M. incognita* (all four races) and *M. javanica* (two races) were widely distributed in the area surveyed during the present investigations. Therefore these nematodes were selected for screening of cultivars of some commonly cultivated vegetables of the area. Seedlings of pepper, eggplant, tomato, cauliflower and cabbage cultivars were raised in clay pots (30 cm) containing autoclaved soil and seedlings raised from surface sterilized seeds (0.01 % mercuric chloride) were later transplanted to individual pots filled with autoclaved soil. Surface sterilized seeds of okra and cucumber cultivars were, however, directly sown in pots. Plants in the 2 to 4 true leaf-stage were inoculated with 5000 freshly hatched second stage juveniles of the races of *M. incognita* and *M. javanica*. Three replicate pots were inoculated for each cultivar. After inoculation, plants were grown for 60 days at a temperature of 27-30°C in glasshouse. After 60 days; plants were removed from pots and roots were thoroughly washed to remove adhered soil particles. Gall index (GI) and reproduction factor (Rf) were determined. Gall index was rated on 0-5 scale of Taylor and Sasser as mentioned under the survey (Section-I).

For determing reproduction factor, nematode reproduction on each cultivar was estimated. All the stages of nematodes and eggs were extracted from the roots separately. For their extraction from the roots separately, chlorox method of Hussey and Barker (1973) was employed, except that the root system was finely chopped in a blender and a 1% NaOCl solution was used. Extracted nematodes and eggs were stained red with a few drops of acid fuchsin acetic acid solution (3.5 g acid fuchsin, 250 ml acetic acid, 750 ml distilled water) and the suspension was boiled briefly (Byrd *et al.*, 1983). Soil population of nematodes was estimated by modified Cobb's sieving and decanting technique (Southey, 1979). The total population/plant (Pf) was estimated and average was calculated. The reproduction factor was then calculated according to formula given by Oostenbrink (1966): R = Pf /Pi, where Pf represented the final population of nematodes and eggs recovered from soil and roots of the cultivars; Pi, the initial population of 5,000 juveniles (J2) with which the plants were inoculated.

Based on gall index and reproduction factor, the host susceptibility of cultivars (degree of resistance) were designated according to the modified scheme of Canto-Saenz (1983) as suggested by Sasser *et al.* (1984) (Table 1).

Table 1. Host suitability designations

Plant damage Gall index	Host efficiency Reproduction factor	Degree of resistance (DR)
≤ 2	≤ 1	Resistant
≤ 2	>1	Tolerent
>2	≤ 1	Hypersusceptible
>2	>1	Susceptible
0	0	Immune

Cultivars were designated as either susceptible = efficient host ($R>1$), significant damage ($GI > 2$); hypersusceptible = poor host ($R\leq1$), singificant damage ($GI > 2$); resistant = poor host ($R \leq 1$), minimal damage ($GI \leq 2$); and all those plants with no nematode reproduction ($R = 0$) and no damage $GI = 0$ was called immune (Sasser *et al.*, 1984).

RESULTS

Response of cultivars of some vegetable crops to root-knot nematodes

Cultivars of seven vegetable crops viz., pepper, eggplant, tomato, okra, cucumber, cauliflower, and cabbage were screened against races 1-4 of *M. incognita* and race A and B of *M. javanica*. Host suitability designations (degree of resistance) was assigned to each cultivar according to their performance against the nematodes. Modified Canto-Saenz scheme (Sasser *et al.,* 1984) was followed for assigning the degree of resistance. Host suitability was based on gall index as indicator of plant damage and on the reproduction factor as an indicator of nematode reproduction (host efficiency) as given in Table 2.

Pepper *(Capsicum annuum)*

Ten cultivars of pepper were tested against the four races of *M. incognita* and two of *M. javanica*. *Six* cultivars namely Patna Red, NP-34, Yolo Wonder, Suryamukhi Green, G-4 and Capsicum F-1-Bharat were found to be susceptible to the races of *M. incognita*. They developed good number of galls and gall index (GI) ranged between 3.0 and 5.0. Thus GI on the cultivars was invariably >2. Egg masses were also produced in good numbers by these nematodes. Reproduction factor (Rf) was invariably >1. Therefore, all cultivars were designated susceptible to the races of *M. incognita*. The reactions of other four cultivars to the races of *M. incognita* were variable. King of North was hypersusceptible to races 1-4. Golden Queen and Suryamukhi Green were susceptible to all the races of *M. incognita* except Golden Queen which was hypersusceptible to race 3. A cultivar named Chilli J-218 was resistant to all the races of *M. incognita*. Another cultivar Ruby King was resistant to races 1-3 and immune to 4 (Table 3).

Table 2. Degree of resistance of some cultivars of vegetable crops tested against *Meloidogyne incognita* (races 1, 2, 3 and 4) and *Meloidogyne javanica* (races A and B)

	M. incognita				*M. javanica*	
Vegetable	Race 1	Race 2	Race 3	Race 4	Race A	Race B
Peper (10)*	S=7, H=1, R=2	S=8, R=2	S=7, H=1, R=2	S=8, R=1, I=1	S=4, R=4, I=2	S=5, R=4, I=1
Eggplant (10)	S=All	S=All	S=All	S=All	S=All	S=All
Tomato (10)	S=9, R=1	S=9, R=1	S=8, H=1, R=1	S=7, H=2, R=1	S=6, H=3, R=1	S=7, H=2, R=1
Okra (10)	S=All	S=All	S=All	S=All	S=All	S=All
Cucumber (10)	S=9, H=1	S=9, H=1	S=9, H=1	S=9, H=1	S=8, H=1, R=1	S=8, H=1, R=1
Cauliflower (10)	S=5, H=2, R=2, I=1	S=4, H=3, R=2, I=1	S=6, H=2, R=1, I=1	S=5, H=2, R=2, I=1	S=4, H=4, R=1, I=1	S=5, H=3, R=1, I=1
Cabbage (10)	S=7, H=2, R=1	S=7, H=2, R=1	S=6, H=3, R=1	S=7, H=2, R=1	S=8, H=1, R=1	S=7, H=2, R=1

* Figure in parentheses in the column is number of cultivars screened.
S=Susceptible; H=Hypersusceptible; R=Resistant; I=Immune.
Figures given against degree of resistance in different columns indicate the number of cultivars assigned to that degree.

Table 3. Host suitability (resistance) of 10 cultivars of pepper to races of *M. incognita*

Cultivars	*M. incognita*															
	Race 1				Race 2				Race 3				Race 4			
	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR
Patna Red	4.0	0.00	4.53	S	3.6	0.58	3.64	S	4.0	0.00	4.76	S	4.6	0.58	6.21	S
King of North	3.3	0.57	0.64	H	3.0	1.00	2.57	S	4.3	0.57	6.48	S	4.0	0.00	4.95	S
NP-34	5.0	0.00	6.78	S	5.0	0.00	5.32	S	3.6	0.58	3.62	S	3.3	0.57	3.42	S
Chilli J-218	1.6	0.58	0.00	R	1.6	0.58	0.63	R	2.0	0.00	0.84	R	0.6	0.58	0.08	R
Ruby King	1.3	0.57	0.06	R	2.0	0.00	0.45	R	1.3	0.57	0.37	R	0.0	0.00	0.00	I
Golden Queen	5.0	0.00	8.42	S	5.0	0.00	6.78	S	3.0	0.00	0.96	H	3.6	0.58	5.43	S
Yolo Wonder	5.0	0.00	12.80	S	5.0	0.00	8.26	S	5.0	0.00	7.13	S	5.0	0.00	10.50	S
Suryamukhi Green	3.0	1.00	3.29	S	3.0	0.00	3.10	S	3.3	0.57	2.88	S	3.3	0.57	2.36	S
G-4	4.6	0.58	7.57	S	4.3	0.57	6.32	S	4.0	000	4.02	S	4.0	0.00	3.62	S
Capsicum F-1 Bharaat	3.0	0.00	2.13	S	3.3	0.57	2.45	S	5.0	0.00	5.34	S	5.0	0.00	9.87	S

GI = Gall index; SD Standard deviation; Rf = Reproduction factor; DR = Degree of resistance.
S = Susceptible; H = Hypersusceptible; R = Resistant; I = Immune.

Of ten cultivars tested against races A and B of *M. javanica,* four cultivars, King of North, Golden Queen, Suryamukhi Green, and G-4 were found to be susceptible. Three cultivars, Patna Red, Chilli J-218 and Yolo Wonder were resistant. Ruby King was immune to both the races as no galling and egg mass production occurred on their roots. The reactions of the remaining two cultivars to the races of *M. javanica* were variable. Cultivar NP-34 was immune to race A and resistant to race B; and Capsicum F-1-Bharat was resistant to race A and susceptible to race B (Table 4).

When degree of resistance of cultivars was analysed for each test nematodes, it was found that seven cultivars were susceptible, two resistant and one hypersusceptible to race 1 of *M. incognita*; eight susceptible and two resistant to race 2; seven susceptible, one hypersusceptible and two resistant to race 3 and eight susceptible, one resistant and one immune to race 4. Four cultivars were susceptible, four resistant and two immune to race A of *M. javanica*, and five susceptible, four resistant and one immune to race B (Table 2).

Eggplant *(Solanum melongena)*

All the ten cultivars of eggplant viz. Vaishali Pant Samart, China Cluster, Brinjal Pragati, Brinjal F1, Deep Purple Round, Ramnagar Giant, P-34, Panipat Round and Batia screened against *M. incognita* (races 1-4) and *M. javanica* (races A and B) were found susceptible. However, plant damage based on gall index (GI) and host efficiency based on reproduction factor (Rf) varied. Gall index (GI) range on the cultivars was between 2-5 (on Brinjal F1 to race A of *M. javanica*) and 5.0 (on several cultivars) and reproduction factor (Rf) range was between 2.04 (Brinjal F1 to race 2 of *M. incognita*) and 25.72 (Batia to race A of

Table 4. Host suitability (resistance) of 10 cultivars of pepper to races of *M. javanica*

Cultivars	*M. javanica*							
	Race A				Race B			
	GI	SD	Rf	DR	GI	SD	Rf	DR
Patna Red	0.6	0.58	0.12	R	1.6	0.58	0.20	R
King of North	4.6	0.58	5.46	S	4.3	0.57	3.78	S
NP-34	0.0	0.00	0.00	I	0.6	0.58	0.31	R
Chilli J-218	1.3	0.57	0.25	R	1.0	0.70	0.18	R
Ruby King	0.0	0.00	0.00	I	0.0	0.00	0.00	I
Golden Queen	2.6	0.58	2.34	S	2.3	0.57	1.46	S
Yolo Wonder	1.0	0.70	0.00	R	1.3	0.57	0.13	R
Suryamukhi Green	4.0	0.00	5.56	S	4.0	0.00	6.04	S
G-4	3.3	0.57	1.72	S	3.0	0.00	1.24	S
Capsicum F-1 Bharaat	2.0	0.00	0.69	R	2.6	0.58	1.72	S

GI = Gall index; SD Standard deviation; Rf = Reproduction factor; DR = Degree of resistance.
S = Susceptible; H = Hypersusceptible; R = Resistant; I = Immune.

M. javanica). Thus GI and Rf of all the test nematodes on each cultivars were >2 and >1 respectively. Consequently all the cultivars were designated as susceptible (Table 5).

Tomato *(Lycopersicon esculentum)*

Ten cultivars of tomato were screened against races 1-4 of *M. incognita* and races A and B of *M. javanica* and their degree of resistance were assigned according to the modified Canto-Saenz scheme (Sasser *et al.*, 1984). On 5 cultivars of tomato viz., Tomato Rashmi, Pusa Ruby, Punjab Kessar, Marglobe and Rutgers, all the test nematodes reproduced efficiently and caused sufficient root galls. The range of reproduction factor was between 3.21 and 26.78. The range of gall index (GI) was between 4.0 and 5.0. On the basis of Rf and GI, all the cultivars were designated as susceptible (Table 6). Tomato Rupali-GS-12 was hypersusceptible to race 3 and 4 of *M. incognita* and races A and B of *M. javanica.* Cultivar S-120 was resistant to all races of *M. incognita* and *M. javanica.* Ponderosa was susceptible to races 1-3 of *M. incognita* and races A and B of *M. javanica* but it was hypersusceptible to race 4. Kalianpur-T1 was susceptible to the all races of *M. incognita* and race B of *M. javanica.* It was hypersusceptible to race A. Cultivar Italian Red Pear was susceptible to the races of *M. incognita* and hypersusceptible to both the races of *M. javanica* (Table 6).

When degree of resistance of cultivars was analysed for each test nematode, it emerged that nine cultivars were susceptible and one was resistant to races 1 and 2 of *M. incognita*; eight cultivars were susceptible, one hypersusceptible and one resistant to race 3, and seven susceptible, two hypersusceptible, and one resistant to race 4. Six cultivars were susceptible, three hypersusceptible and one resistant to race

Table 5. Host suitability (resistance) of 10 cultivars of eggplant to races of *M. incognita* and *M. javanica*

Cultivars	*M. incognita*																*M. javanica*							
	Race 1				Race 2				Race 3				Race 4				Race A				Race B			
	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR
Vaishali	5.0	0.00	10.42	S	5.0	0.00	5.82	S	5.0	0.00	4.23	S	5.0	0.00	7.56	S	5.0	0.00	8.60	S	5.0	0.00	674	S
Pant Samart	4.3	0.57	7.75	S	4.0	0.00	4.41	S	3.6	0.58	5.32	S	3.3	0.57	3.66	S	4.6	0.58	7.12	S	4.3	0.57	5.32	S
China Cluster	5.0	0.00	18.64	S	5.0	0.00	10.72	S	5.0	0.00	6.82	S	5.0	0.00	12.24	S	5.0	0.00	13.56	S	5.0	0.00	10.25	S
Brinjal Prajati	3.3	0.57	2.76	S	3.3	0.57	2.80	S	3.6	0.58	2.62	S	3.3	0.58	2.73	S	2.6	0.58	2.45	S	3.3	0.57	2.12	S
Brinjal F-1	3.6	0.58	4.76	S	3.0	0.00	2.04	S	3.3	0.57	2.44	S	3.6	0.58	2.82	S	3.3	0.57	3.98	S	3.6	0.58	2.46	S
Deep Purple Round	5.0	0.00	25.13	S	5.0	0.00	23.24	S	5.0	0.00	19.33	S	5.0	0.00	14.25	S	3.0	0.00	4.10	S	3.0	0.00	3.13	S
Ram Nagar Giant	5.0	0.00	10.57	S	5.0	0.00	14.56	S	4.0	0.00	8.62	S	4.6	0.58	7.46	S	4.6	0.58	6.99	S	4.3	0.57	7.28	S
P-34	5.0	0.00	13.60	S	5.0	0.00	5.84	S	5.0	0.00	12.26	S	5.0	0.00	9.86	S	5.0	0.00	12.47	S	5.0	0.00	9.47	S
Panipat Round	5.0	0.00	17.50	S	5.0	0.00	14.10	S	5.0	0.00	16.21	S	5.0	0.00	10.54	S	5.0	0.00	15.24	S	5.0	0.00	16.00	S
Batia	5.0	0.00	24.89	S	5.0	0.00	19.40	S	5.0	0.00	12.75	S	5.0	0.00	1111	S	5.0	0.00	25.72	S	5.0	0.00	23.71	S

GI = Gall index; SD = Standard deviation; Rf = Reproduction factor; DR = Degree of resistance.
S = Susceptible; H = Hypersusceptible; R = Resistant; I = Immune.

A of *M. javanica;* and seven were susceptible, two hypersusceptible and one resistant to race B (Table 2 and 6).

Okra ***(Abelmoschus esculentus)***

All the ten cultivars of okra screened against races of *M. incognita* and *M. javanica* were found to be susceptible as GI and Rf ranges were between 2.3 (Lucknow Dwarf to race 3 of *M. incognita*) and 5.0 (several); and 2.23 (Parbhani Kranti to race B of *M. javanica*) and 22.00 (Long White to race 1 of *M. incognita*) respectively. Thus according to the modified Canto-Saenz scheme all cultivars belonged to the susceptible category (Table 7). This implies that all the cultivars were efficient host of the four races of *M. incognita* and two races of *M. javanica* and may suffer significant damage if grown in fields infested with these nematode populations.

Cucumber ***(Cucumis sativus)***

Of ten cultivars of cucumber tested against the races of *M. incognita* and of *M. javanica,* eight cultivars viz., Straight Eight, Balam Khira, Japanese Long Green, Telegaon Super White, Cucumber-F1, Poona Khira White, Tar Kakri and Point Sett were found to be susceptible to all the test nematodes. On these cultivars gall index (GI) ranged between 2.3 and 5.0 and reproduction factor (Rf) range was between 1.5 and 14.6. Cultivar All Season was hypersusceptible to all the test nematodes. Cultivar Improved Long Green was susceptible to the races of *M. incognita* but resistant to the races of *M. javanica* (Table 8).

When degree of resistance of cultivars were analysed for each test nematode, it was observed that nine cultivars were susceptible and one hypersusceptible to all the four races of *M. incognita.* Eight cultivars were susceptible, one hypersusceptible and one resistant to races A and B of *M. javanica* (Table 2 and 8).

Table 6. Host suitability (resistance) of 10 cultivars of tomato to races of *M. incognita* and *M. javanica*

Cultivars	*M. incognita*																*M. javanica*							
	Race 1				Race 2				Race 3				Race 4				Race A				Race B			
	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR
Tomato Rashmi Vaishali	5.0	0.00	7.43	S	4.0	0.00	4.56	S	4.0	0.00	3.21	S	5.0	0.00	9.85	S	4.0	0.00	5.67	S	4.0	0.00	4.84	S
Tomato Rupali GS-12	3.3	0.57	2.26	S	3.0	1.00	2.08	S	3.3	0.57	0.78	H	3.0	1.0	0.42	H	3.0	1.00	1.00	H	3.3	0.57	0.56	H
Pusa Ruby	5.0	0.00	19.35	S	5.0	0.00	12.72	S	5.0	0.00	8.54	S	5.0	0.00	7.53	S	5.0	0.00	23.41	S	5.0	0.00	18.77	S
Punjab Kessar	4.0	0.00	6.84	S	5.0	0.00	10.13	S	4.0	0.00	7.64	S	5.0	0.00	12.14	S	4.0	000	7.32	S	4.0	0.00	6.32	S
S-120	1.0	0.00	0.40	R	0.6	0.98	0.53	R	1.3	1.22	0.25	R	1.0	0.70	0.22	R	1.0	0.00	0.62	R	1.6	0.58	0.43	R
Ponderosa	3.3	0.57	3.07	S	3.0	0.00	2.64	S	3.6	0.58	1.89	S	3.3	0.57	0.98	H	3.3	0.57	2.88	S	3.0	1.00	2.64	S
Marglobe	5.0	0.00	14.71	S	5.0	0.00	16.87	S	5.0	0.00	14.42	S	5.0	0.00	8.36	S	5.0	0.00	10.54	S	5.0	0.00	9.15	S
Kalianpur-T1	3.0	1.00	5.38	S	3.3	0.57	3.40	S	3.0	0.00	2.13	S	2.6	0.58	2.20	S	3.3	0.57	0.73	H	3.0	0.00	1.68	S
Italian Red Pear	4.6	0.58	8.56	S	4.3	0.57	6.32	S	4.0	0.00	3.90	S	4.0	0.00	5.74	S	3.0	1.00	0.62	H	3.3	0.57	0.33	H
Rutgers	5.0	0.00	26.78	S	5.0	0.00	22.26	S	5.0	0.00	15.87	S	5.0	0.00	14.52	S	5.0	0.00	22.43	S	5.0	0.00	18.12	S

GI = Gall index; SD = Standard deviation; Rf = Reproduction factor; DR = Degree of resistance.
S = Susceptible; H = Hypersusceptible; R = Resistant.

Table 7. Host suitability (resistance) of 10 cultivars of okra to races of *M. incognita* and *M. javanica*

Cultivars	*M. incognita*																*M. javanica*							
	Race 1				Race 2				Race 3				Race 4				Race A				Race B			
	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR
Red Wonder	5.0	0.00	17.80	S	5.0	0.00	8.85	S	5.0	0.00	7.35	S	5.0	0.00	11.94	S	5.0	0.00	10.26	S	5.0	0.00	8.54	S
Long White	5.0	0.00	22.00	S	5.0	0.00	15.66	S	5.0	0.00	12.22	S	5.0	0.00	9.36	S	4.6	0.00	7.11	S	4.3	0.57	6.32	S
Lucknow Dwarf	3.6	0.58	5.34	S	3.3	0.57	30.17	S	2.3	0.57	2.44	S	3.6	0.58	6.78	S	3.0	0.58	2.87	S	3.0	0.00	2.89	S
Valvet Green	4.0	0.00	8.75	S	4.0	0.00	6.24	S	4.6	0.58	10.96	S	3.6	0.58	3.09	S	3.3	0.58	4.63	S	3.0	0.00	3.15	S
Parbhani Kranti	3.3	0.57	2.96	S	3.6	0.58	2.52	S	3.0	0.00	3.25	S	3.0	0.00	4.46	S	2.3	0.00	2.42	S	2.6	0.58	2.23	S
Punjab Padmini	3.0	0.00	6.59	S	3.0	0.00	4.43	S	3.0	0.00	5.63	S	4.6	0.58	8.27	S	3.0	0.58	3.05	S	3.0	0.00	2.76	S
Padra Shankar Pali	5.0	0.00	20.23	S	5.0	0.00	17.78	S	4.6	0.58	9.85	S	5.0	0.00	15.13	S	5.0	0.00	18.94	S	5.0	0.00	13.61	S
Pusa Makhmali	4.0	0.00	7.97	S	3.6	0.58	5.56	S	3.3	0.57	4.37	S	3.0	0.00	3.54	S	3.3	0.00	4.22	S	3.6	0.58	3.34	S
Silver Thabua	5.0	0.00	14.41	S	5.0	0.00	11.39	S	5.0	0.00	12.24	S	5.0	0.00	10.76	S	4.6	0.00	9.66	S	4.3	0.57	7.28	S
Smooth Velvet	5.0	0.00	10.24	S	4.3	0.57	7.97	S	4.6	0.58	6.43	S	5.0	0.00	12.32	S	4.0	0.00	8.53	S	4.3	0.57	6.52	S

GI = Gall index; SD = Standard deviation; Rf = Reproduction factor; DR = Degree of resistance.
S = Susceptible; H = Hypersusceptible; R = Resistant.

Table 8. Host suitability (resistance) of 10 cultivars of cucumber to races of *M. incognita* and *M. javanica*

Cultivars	*M. incognita*																*M. javanica*							
	Race 1				Race 2				Race 3				Race 4				Race A				Race B			
	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR
Straight Eight	4.6	0.58	4.15	S	4.3	0.57	3.20	S	4.0	0.00	5.67	S	4.0	0.00	5.67	S	3.3	0.57	2.84	S	3.6	1.15	2.78	S
Balam Khira	2.6	0.58	2.30	S	2.3	0.57	2.25	S	3.3	0.57	4.32	S	3.6	0.57	4.32	S	3.0	0.00	4.67	S	3.0	0.00	2.34	S
Japanese Long Green	5.0	0.00	7.56	S	5.0	0.00	4.13	S	3.0	0.00	3.16	S	3.0	0.00	3.16	S	3.0	0.00	3.31	S	3.0	0.00	2.27	S
Telegaon Super White	3.3	0.57	2.25	S	2.3	0.57	2.50	S	3.0	0.00	6.75	S	3.6	0.00	6.75	S	3.3	0.57	4.00	S	2.6	0.58	2.45	S
Cucumber-F1	4.0	0.00	3.42	S	3.6	0.58	2.46	S	3.3	0.57	2.53	S	4.3	0.57	2.53	S	2.3	0.57	1.58	S	3.3	0.57	2.63	S
Poona Khira White	5.0	0.00	14.67	S	5.0	0.00	5.34	S	5.0	0.00	7.24	S	5.0	0.00	7.24	S	5.0	0.00	9.43	S	5.0	0.00	5.56	S
Tar Kakri	5.0	0.00	12.74	S	5.0	0.00	7.62	S	5.0	0.00	8.43	S	5.0	0.00	8.43	S	5.0	0.00	7.72	S	5.0	0.00	6.92	S
All Season	3.0	0.00	0.82	H	3.3	0.57	1.00	H	3.6	0.58	0.95	H	2.6	0.58	0.95	H	2.3	0.57	0.46	H	2.6	0.58	0.64	H
Point Selt	4.0	0.00	2.95	S	4.3	0.57	2.18	S	4.6	0.58	2.66	S	4.0	0.58	2.66	S	5.0	0.00	4.57	S	5.0	0.00	3.34	S
Improved Long Green	4.3	0.57	4.12	S	3.6	0.58	3.90	S	3.3	0.57	3.22	S	4.3	0.57	3.22	S	1.0	0.00	0.62	S	1.3	0.57	0.66	R

GI = Gall index; SD = Standard deviation; Rf = Reproduction factor; DR = Degree of resistance.
S = Susceptible; H = Hypersusceptible; R = Resistant.

Cauliflower *(Brassica oleracea* var. *botrytis)*

Ten cultivars of cauliflower were screened against all the races of *M. incognita* and *M. javanica.* Three cultivars namely Kunwari, Summer Sweet Heart and Padam Shree were found to be susceptible to all the test nematodes as gall index (GI) was >2 and reproduction factor (Rf) was >1 (GI range 2.3 and 5.0 and Rf 2.00 and 7.36). The reactions of other seven cultivars to the races of *M. incognita* and *M. javanica* were variable. Cultivar Early Market was susceptible to races 1, 2 and 4 but hypersusceptible to race 3 of *M. incognita* and race A and race B of *M. javanica.* Cultivar Giant Snowball was hypersusceptible to races 1, 2 and 4; and susceptible to race 3 of *M. incognita.* This cultivar was also susceptible to race A and hypersusceptible to race B of *M. javanica.* Cultivar Main Crop Patna was hypersusceptible to races 1 and 2 and susceptible to races 3 and 4 of *M. incognita*; and hypersusceptible to race A and susceptible to race B of *M. javanica.* Bharat Ratna was resistant and cultivar 96-D was immune to all the four races of *M. incognita* and the two races of *M. javanica.* Cultivar Vishwa Bharti was resistant to races 1, 2 and 4 and hypersusceptible to race 3 of *M. incognita* and race A and B of *M. javanica.* Cultivar China Pearl Snowball was susceptible to races 1 and 3 of *M. incognita* and race B of *M. javanica*; and hypersusceptible to race 2, and 4 of *M. incognita* and race A of *M. javanica* (Table 9).

When degree of resistance of cultivars were analysed for each test nematode, five cultivars were found to be susceptible, two hypersusceptible, two resistant and one immune to race 1 and 4 of *M. incognita*; four susceptible, three hypersusceptible, two resistant and one immune to race 2; six susceptible, two hypersusceptible, one resistant and one immune to race 3. Four cultivars were susceptible, four hypersusceptible, one resistant and one immune to race A; and five susceptible, three hypersusceptible, one resistant and one immune to race B of *M. javanica* (Table 2 and 9).

Cabbage *(Brassica oleracea* var. *capitata)*

Ten cultivars of cabbage were screened against the races of *M. incognita* and *M. javanica*. Three cultivars viz., Express Flat, Early Pathari and Indian Pride were susceptible to all the test nematodes, as on all these cultivars GI was >2 and Rf was >1 (Table 10). Remaining cultivars showed variable reactions to the different test nematodes. Indian Eclipse was susceptible to races 1, 2and 4 of *M. incognita* and races A and B of *M. javanica* and hypersusceptible to race 3 of *M. incognita*. Brunswick was susceptible to all the four races of *M. incognita* and hypersusceptible to both the races of *M. javanica*. Canarian was susceptible to races 1, 2 and 4 of *M. incognita* and race A of *M. javanica*; hypersusceptible to race 3 of *M. incognita* and race B of *M. javanica*. Early Drum Head was susceptible to race 1 of *M. incognita* and both races of *M. javanica*; and hypersusceptable to races 2, 3 and 4 of *M. incognita*. Early Queen was, however resistant to all the test nematodes. Queen of Queens was hypersusceptible to races 1 and 2 of *M. incognita* but susceptible to rest of the pathogen. Sutton's Earliest was hypersusceptible to races 1 and 4 of *M. incognita*; and susceptible to rest of the nematodes (Table 10).

When degree of resistance of cultivars were analysed for each test nematodes, seven cultivars emerged susceptible, two hypersusceptible and one resistant to races 1 and 2 of *M. incognita*. Six cultivars were susceptible; two hypersusceptible and 2 resistant to race 3; seven susceptible, two hypersusceptible; one resistant to race 4 of *M. incognita*.

Table 9. Host suitability (resistance) of 10 cultivars of cauliflower to races of *M. incognita* and *M. javanica*

Cultivars	*M. incognita*																*M. javanica*							
	Race 1				Race 2				Race 3				Race 4				Race A				Race B			
	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR
Kunwari	3.3	0.57	2.73	S	3.6	0.58	3.26	S	3.0	0.00	3.08	S	3.3	0.57	2.94	S	2.6	0.58	2.13	S	2.3	0.57	2.00	S
Early Market	3.6	0.58	3.45	S	3.0	0.00	2.74	S	2.6	0.58	0.78	H	3.6	0.58	2.43	S	2.3	0.57	0.82	H	2.6	0.58	0.56	H
Giant Snowball	3.0	0.00	0.98	H	2.3	0.57	0.65	H	3.0	1.00	2.15	S	3.0	0.00	0.86	H	3.0	0.00	2.20	S	3.0	0.00	0.88	H
Main Crop Patna	2.6	0.58	0.44	H	3.0	0.00	1.00	H	3.0	0.00	2.64	S	3.3	0.70	2.92	S	3.0	1.00	0.62	H	3.3	0.57	2.37	S
Bharat Ratna	1.6	0.58	0.0	R	2.0	0.00	0.37	R	0.6	0.58	0.77	R	1.3	0.70	0.64	R	1.6	1.02	0.76	R	1.3	0.57	0.65	R
Summer Sweet Heart	5.0	0.00	7.36	S	5.0	0.00	6.18	S	4.6	0.58	4.53	S	4.3	0.57	3.20	S	4.0	0.00	3.43	S	4.0	0.00	3.40	S
96-D	0.0	0.00	0.00	I	0.0	0.00	0.00	I	0.0	0.00	0.00	I	0.0	0.00	0.00	I	0.0	0.00	0.00	I	0.0	0.00	0.00	I
Vishwa Bharti	0.6	0.58	0.23	R	1.6	0.58	0.00	R	3.3	0.57	0.60	H	1.3	0.57	0.61	R	3.0	0.00	0.57	H	3.6	0.58	0.62	H
Padam Shree	3.6	0.58	4.09	S	4.0	1.00	5.74	S	3.3	1.52	5.04	S	5.0	0.00	4.16	S	5.0	0.00	5.70	S	4.3	0.57	4.73	S
China Pearl Snow Ball	2.3	1.15	1.56	S	2.6	0.58	0.99	H	3.0	0.00	1.59	S	2.6	1.72	0.53	H	3.0	0.00	0.49	H	2.6	0.58	1.38	S

GI = Gall index; SD = Standard deviation; Rf = Reproduction factor; DR = Degree of resistance.
S = Susceptible; H = Hypersusceptible; R = Resistant; I = Immune.

Table 10. Host suitability (resistance) of 10 cultivars of cabbage to races of *M. incognita* and *M. javanica*

Cultivars	*M. incognita*																*M. javanica*							
	Race 1				Race 2				Race 3				Race 4				Race A				Race B			
	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR	GI	SD	Rf	DR
Express Flat	4.0	0.00	5.20	S	4.0	0.00	3.20	S	4.0	0.00	4.56	S	4.0	0.00	6.31	S	4.6	0.58	4.36	S	3.6	0.58	3.55	S
Early Pathari	5.0	0.00	7.64	S	5.0	0.00	6.71	S	5.0	0.00	2.34	S	5.0	0.00	8.56	S	4.00	0.00	5.52	S	4.0	0.00	4.67	S
Early Drum Head	2.6	0.58	2.83	S	2.3	0.57	0.72	H	2.6	0.58	0.83	H	2.6	0.58	0.77	H	3.6	0.58	2.78	S	3.3	0.57	2.43	S
Early Queen	2.0	0.00	0.00	R	0.6	0.98	0.43	R	0.6	0.98	0.31	R	0.6	0.98	0.48	R	2.0	0.00	0.22	R	0.6	0.98	0.34	R
Queen of Queens	3.0	0.00	0.98	H	3.0	0.00	0.66	H	4.0	0.00	2.67	S	4.0	0.00	4.62	S	3.0	0.00	3.24	S	3.0	0.00	2.26	S
Sutton's Earliest	3.3	0.57	0.86	H	4.0	0.00	2.34	S	4.0	0.00	3.28	S	2.3	0.57	0.71	H	3.6	0.58	2.01	S	3.3	0.57	2.12	S
Indian Eclipse	4.3	0.57	3.95	S	4.0	0.00	3.24	S	3.0	0.00	1.00	H	3.0	0.00	2.40	S	4.6	0.58	6.30	S	4.0	0.00	3.21	S
Brunswick	4.0	0.00	5.64	S	3.6	0.58	2.70	S	4.3	0.57	4.10	S	4.0	0.00	3.25	S	3.6	0.58	0.85	H	3.3	0.57	0.66	H
Indian Pride	5.0	0.00	8.72	S	5.0	0.00	5.58	S	5.0	0.00	3.42	S	5.0	0.00	5.14	S	5.0	0.00	4.23	S	5.0	0.00	4.00	S
Canarian	4.0	0.00	6.11	S	4.0	0.00	4.36	S	3.0	0.00	0.24	H	4.0	0.00	2.67	S	3.0	0.00	1.34	S	3.0	0.00	0.89	H

GI = Gall index; SD = Standard deviation; Rf = Reproduction factor; DR = Degree of resistance.
S = Susceptible; H = Hypersusceptible; R = Resistant.

Eight cultivars were found susceptible, one hypersusceptible and one resistant to race A; and seven susceptible, two hypersusceptible and one resistant to race B of *M. javanica* (Table 2 and 10).

DISCUSSION

Use of host resistance is an effective and economic management measure for root-knot nematodes. Nematicides, both soil fumigants and systemics are effective against root-knot nematodes and have been successfully used for management of root-knot disease on a large number of crops (Ferry and Dukes, 1984). Application of nematicides have several disadvantages and for this reason their use is gradually declining. Most of the soil fumigants have been banned from manufacturing. For low value crops their application is also costly (Fassuliotis, 1979). Residues in consumable parts of the plants, contamination of groundwater and other health hazards are associated with their use. For these reasons, emphasis has shifted from chemical to non-chemical measures. Recognition of occurrence of races in *M. incognita, M. arenaria* and *M. chitwoodi* opened new areas of research. Variations in host preferences of the races in mixed populations of the species is also an impediment for the successful use of host resistance for root-knot management. Fassuliotis (1985) rightly suggested that many, if not all of the cultivars already reported to have some resistance will have to be re-evaluated because previously reported resistance may be race specific. From the IMP data, it is apparent that, a crop having resistance to all the races of *M. incognita* and *M. javanica* would be resistant to 82% of the *Meloidogyne* populations around the world. (Fassuliotis, 1979).

In the past, attempts were made by a number of workers in different parts of the world to evaluate the cultivars of crops for their resistance. But the inoculum levels and parameters or scales for measuring the resistance of the cultivars varied and consequently the degree of resistance assigned to cultivars were different in different studies. In the present investigation a standard method as suggested by Sasser *et al.*

(1984) was applied and 10 cultivars of each vegetable crop like pepper, eggplant, tomato, okra, cucumber, cauliflower and cabbage were screened against races 1-4 of *M. incognita* and newly differentiated populations of *M. javanica,* tentatively designated as race A and race B in order to evaluate their degree of resistance, so that cultivars showing resistance can be used by growers for root-knot free crops. Most of the cultivars of the vegetables are susceptible (Table 1-8). In pepper, of the 10 cultivars, Suryamukhi Green and G-4 were susceptible to all the races of *M. incognita* and *M. javanica.* Cultivar King of North and Golden Queen were also susceptible to all the test nematodes except race 1 and race 3 of *M. incognita* respectively. Only cultivar Chilli J-218 was resistant to all the races of *M. incognita* and *M. javanica.* Ruby King was also resistant to races 1-3 but immune to race 4 of *M. incognita* and races A and B of *M. javanica.* Remaining cultivars showed race-specific resistance (Table 2).

Despite general belief that *M. javanica* is non-pathogenic on pepper, pathogenic variability has been reported among the different populations of the *M. javanica* (Jain *et al.* 1983; Khan, 1988; Walia and Gupta, 1986; Stephan, 1988; Rammah and Hirschmann, 1990; Khan and Khan, 1991b). *M. javanica* was found infecting pepper plants. Jain *et al.* (1983) found a number of pepper cultivars susceptible to *M. javanica.* Similar reports was made by Walia and Gupta (1986). Khan (1988) observed that pepper was often infected with *M. javanica* in vegetable fields in Uttar Pradesh, India. Khan and Khan (1991b) rated a number of cultivars of pepper as immune or resistant but a few were designated as hypersusceptible and susceptible to populations of *M. javanica.* These studies indicate towards two possibilities, first is related to pathogenic variability in *M. javanica* populations; second is related to the variations in susceptibility of cultivars to a single population of *M. javanica.* In the present study, the findings corroborate previous results of some studies that *M. javanica* in India is infective on pepper and may cause plant damage even to hypersusceptible cultivars and population growth of species is expected on susceptible cultivars. At the same time, it shows that pathogenic variability exists in *M. javanica* populations in the country.

Pepper was reported as good host of *M. incognita* (Alam *et al.*, 1974; Taylor and Sasser, 1978; Khan, 1988). In the present study, several cultivars were susceptible to either one or other races of *M. incognita.* Khan and Khan (1991b) also found race-specific resistance in pepper to *M. incognita* races. The long term management strategy for *M. incognita* infestation of pepper by breeding cultivars resistant to the various races demands greater attention than at present. The study suggests that race resistant cultivars may be grown in specific race infestations.

All the 10 cultivars of eggplant were rated susceptible to all the test nematodes and no race-specific resistance was exhibited (Table 2). This implies that all cultivars were good hosts to the nematodes on which they could multiply efficiently. These cultivars of eggplant are liable to suffer great damages if grown in fields infested with *M. javanica* and *M. incognita.* In past also no cultivar has been found resistant to *Meloidogyne* species (Khan, 1988; Khan and Khan, 1990; Verma, 1978). There is a great need to develop cultivars of eggplant with resistance against nematodes especially to all the 4 races of *M. incognita* and races A and B of *M. javanica.*

Of the 10, only one cultivar S-120 of tomato was resistant to all the 4 races of *M. incognita* and races A and B of *M. javanica* (Table 3).

Five cultivars were susceptible to all the races of *M. incognita* and *M. javanica*. These cultivars were also reported susceptible by Taylor and Sasser (1978), Khan (1988), Khan and Khan (1991c), Jain *et al.* (1983); Verma (1978); and Yassin and Zaidan (1982). Cultivar Tomato Rupali was also susceptible to races 1 and 2 but hypersusceptible to race 3 and race 4 of *M. incognita* and races A and B of *M. javanica*. Cultivar Kalianpur-T_1; Italian Red Pear and Ponderosa were hypersusceptible to race A and race B of *M. javanica* and race 4 of *M. incognita* respectively. A number of cultivars of tomato were susceptible to races of *M. javanica* and *M. incognita* according to degree of resistance determined in the present study. As these susceptible cultivars are efficient hosts, significant damage may occur in field plots infested with these nematodes.

All okra cultivars, were found susceptible to all the four races of *M. incognita* and races A and B of *M. javanica* in the present study. In view of this, adequate management measures are required if such okra cultivars are to be grown in *M. incognita* or *M. javanica* infested soil, irrespective of the races.

Most of the cucumber cultivars were susceptible/hypersusceptible to all the test nematodes except improved Long Green which showed resistance against race A of *M. javanica*. Khan and Khan (1989) also found Improved Long Green resistant to *M. javanica*. This cultivar (Improved Long Green) can be utilized by growers for the fields infested with *M. javanica*.

Of the 10 cauliflower cultivars, 96-D proved immune and Bharat Ratna resistant to all the test nematodes. Cultivars Vishwa Bharti was resistant to race 1, 2 and race 4 but hypersusceptible to race 3 of *M. incognita* and race A and race B of *M. javanica*. Rest of the cultivars were susceptible or showed race-specific resistance. Sources of resistance to races of *M. javanica* and *M. incognita* detected in this study may be useful in breeding programmes. Similar results for cauliflower cultivars were also obtained in the experiments conducted by Khan and Khan (1991d). Except Early Queen, all cultivars of cabbage were either susceptible or hypersusceptible to all races of *M. incognita* and *M. javanica* (Table 8). This cultivar could be used as a source of resistant germplasm to these pathogens.

Most of the cultivars of the vegetable crops, included in the present study were susceptible and some showed differential response being race-specific. Therefore, it is suggested that such cultivars of the vegetable crops should not be grown in the root-knot infested fields. Prior to recommendation of the cultivars that have shown differential response for cultivation, it is essential to determine the nature of infestation with reference to species and race content of the filed or area to be grown and recommendations should be made accordingly.

Host resistance is an important natural source for the management of plant diseases including root-knot nematodes. But a few cultivars that are commercially grown have shown resistance. Possibly breeding programmes for vegetable cultivars in India and other countries have not given adequate attention to root-knot problem. This does not augur well for root-knot free cultivation of vegetables. Multiple species and multiple race infestation of vegetables fields further compounds the problem and it becomes more difficult to manage root-knot disease. Efforts should be made at global level to evolve cultivars of vegetables possessing multiple resistance against all the 4 major species and races of root-knot nematodes such efforts are being made for tomato at the Asian Vegetables Research and Development Centre (AVRDC), Taiwan. Other vegetable crops also deserve similar attention.

SUMMARY

Cultivars of seven vegetable crops namely pepper, eggplant, tomato, okra, cucumber, cauliflower and cabbage were screened against all the four races of *M. incognita* and two newly and tentatively designated races of *M. javanica* in order to evaluate their degree of resistance and locate sources of resistance.

Most of the cultivars of the vegetables screened were susceptible to races 1-4 of *M. incognita* and races A and B of *M. javanica.* All the cultivars of eggplant and okra and most of the cultivars of cucumber were susceptible to all the test nematodes. On the other hand, some cultivars of pepper, tomato, cauliflower and cabbage, showed resistance to one or other test nematode.

In pepper, out of the 10 cultivars included only two cultivars, Ruby King and Chilli J-218 were resistant/immune and Suryamukhi Green and G-4 were susceptible to all the test namatodes. However, other cultivars showed variable responses. Cultivars King of North and Golden Queen were hypersusceptible to race 1 and race 3 of *M. incognita,* respectively. Rest of the cultivars were susceptible to all the races of *M. incognita.* Cultivars Patna Red, NP-34, Yolo Wonder and Capsicum F-1 Bharat were resistant/immune to race A or race B of *M. javanica.*

None of the 10 cultivars of eggplant and okra screened showed resistance to races of *M. incognita* and *M. javanica.* In cucumber, out of 10 cultivars included, eight were found to be susceptible and one (All Season) hypersusceptible to all the test nematodes. Improved Long Green alone showed resistance to both race A and race B of *M. javanica* but it was susceptible to all the four races of *M. incognita.*

Of the 10 cultivars of tomato screened, one cultivar, S-120 was resistant and five cultivars viz., Tomato Rashmi, Pusa Ruby, Punjab Kessar, Marglobe and Rutgers were susceptible to all the test nematodes. Other cultivars were either susceptible or hypersusceptible to all races of *M. incognita* and *M. javanica.*

Among cauliflower cultivars screened, only Bharat Ratna and 96-D were resistant and immune respectively to all of races of *M. incognita* and *M. javanica.* Cultivars like Kunwari, Summer Sweet Heart and Padam Shree were susceptible to all the test nematodes. Other cultivars were susceptible or hypersusceptible to all the races of *M. incognita* and *M. javanica.*

The reaction of 10 cultivars of cabbage used in the study varied according to test nematode. A single cultivar of cabbage Early Queen was resistant and three cultivars viz., Express Flat, Early Pathari and Indian Pride were susceptible to all the test nematodes. Cultivar Early Drum Head was hypersusceptible to race 2, race 3 and race 4 of *M. incognita.* Remaining cultivars were susceptible and only a few were hypersusceptible to all the 4 races of *M. incognita* and 2 races of *M. javanica.*

SECTION - III

Interaction Studies

LITERATURE REVIEW

Ample opportunities for interaction between species of plant parasitic nematodes exist as they occur in polyspecific communities (Oostenbrink, 1966). Members of nematode communities constantly interact with each other (Eisenback, 1985). Interactions of the nematodes may be interspecific or interaspecific. Irrespective of interaspecific or interspecific influences the host plant. In the respect of host damage, the interaction may be negative, positive or neutral. If the disease severity caused by the interacting nematodes is less than the total of their individual effect, the interaction is negative; if it is more, the interaction is positive; and if it is same i.e. simply additive, there is no interaction (neutral) (Wallace, 1978). The interactions between the nematodes are usually negative and may be categorized as competition resource use type (Khan, 1984). In this type of negative interaction each population adversely affects the other or only one of them is suppressed as the interacting nematodes compete for the same resource which is in short supply. Some instances of positive interaction of nematode species have been reported (Eisenback, 1985). According to Norton (1978) negative interactions in nematodes can be caused by a spatial occupation or physical alteration or destruction of feeding sites or by a physiological alteration of the host that decrease its suitability.

Application of the Gause's principle of competitive exclusion (Gause, 1934) the nematode communities is difficult, because the soil environment contains many different niches that are dynamic and thus are not easily demarcated (Eisenback. 1985). Nematode-nematode interactions may involve ectoparasites and endoparasites; ecto, and semi-endoparasites; semi-endo; and endoparasites or species with similar modes of parasitism. The mode of parasitism plays an important role in the interaction effects of nematodes on plants as well as in their own population growths

(Khan, 1984). Competition is more vigorous between the species of similar feeding habits and interactive effects become discernible with increasing complexity of host. Various aspects of nematode-nematode interactions have been reviewed from time to time by Norton (1978), Khan (1981), Khan (1984), Eisenback (1985), Eisenback and Griffin (1987), Khan and Khan (1988), Eisenback (1993).

Interactions between *Meloidogyne* and semi-endoparasites

Interactions between migratory and sedentary endoparasites or between migratory or sedentory semi-endoparasites have been studied on a number of plants (Eisenback, 1985, 1993; Eisenback and Griffin, 1987). Migratory endoparasites are very competitive with each other as they have common feeding sites. Suitability of the host for the cohabiting nematodes plays significant role in such type of interactions (Eisenback, 1985). Sedentary endoparasites are highly specialized parasites, and develop a complex relationship with the host and the host physiology is greatly altered (Jones, 1981). As the sedentary endoparasites compete for the nutrition and feeding sites in the same host plant, their interaction is generally mutually suppressive (Khan *et al.,* 1986b, 1987). Migration of migratory endoparasites within the root tissue disturbs feeding of sedentary endoparasites. They often penetrate the host faster or inhibit penetration by sedentary endoparasites. This is not, however, always true. In contrast, sedentary endoparasites stimulate or suppress penetration of migratory endoparasites depending upon the host suitability (Eisenback, 1993). Interaction of endoparasitic nematodes is influenced by relative susceptibility of the interacting species. Gay and Bird (1973) demonstrated that on tomato, which was better host for *M. incognita* than *P. brachyurus*, prior inoculations of *M. incognita* suppressed penetration of *P. brachyurus*. On cotton, however, which was a good host for

M. incognita, prior inoculation by *M. incognita* slightly stimulated penetration of *P. brachyurus*. Khan *et al.* (1986a, 1986b) observed that on tomato and eggplant which was a good host for *M. incognita* and *R. reniformis*, in simultaneous inoculation of the species, the multiplication rate of both declined when compared with single species inoculation at the same inoculum levels. However, no such interaction between the species was observed on cauliflower which was not a good host for both (Khan *et al.* 1987). Johnson and Nusbaum (1970) studied the interactions between *M. incognita*, *M. hapla* and *P. brachyurus* in greenhouse experiments on four cultivars of tobacco and noticed that tobacco cv. 'Hicks' and 'NC2326' were susceptible to each nematode and cv. 'NC 95' and 'NC 2521' were resistant to *M. incognita* only. *M. incognita* and *P. brachyurus* were mutually suppressive on 'NC 2326'. However, no effect of *P. brachyurus* was obtained on 'Hicks' but *M. incognita* suppressed *P. brachyurus*. On tobacco cv. 'NC 95' and 'NC 2521' which were resistant to *M. incognita*, *P. brachyurus* was stimulated. In interaction between *M. hapla* and *P. brachyurus*, mutual suppressive effects were observed on tobacco cv. 'Hicks' but on 'NC 95' only *M. hapla* and on 'NC 23261' *P. brachyurus* were found on 'NC 2521'. Sikora *et al.* (1972) observed that *Pratylenchus penetrans* initially inhibited *Meloidogyne naasi* on creeping bentgrass, but after ten months such inhibitory effect was not found. Amosu and Taylor (1975) reported that *M. incognita* had no effect on a population of *P. penetrans* on red clover in greenhouse experiments after three months, but suppression occurred after five months.

The interaction between migratory and sedentary endoparasites is also affected by the population density of the interacting nematodes. Chapman and Turner (1972) observed that egg deposition of

P. penetrans was differentially affected by the varying density of *M. incognita* in concomitant populations. Egg deposition of *P. penetrans* was reduced by 37% in the presence of low number of *M. incognita*. But in the presence of high number of *M. incognita*, 57% reduction occurred. In a greenhouse study, it has been shown that low numbers of *P. penetrans* were greatly inhibited by *Globodera tabacum* on tobacco but high numbers of *P. penetrans* greatly suppressed *G. tabacum* (Miller, 1970).

Several interactions between migratory and sedentary endoparasites have been found to be mutually suppressive for interacting nematodes. Estores and Chen (1970, 1972) found that the populations of *P. penetrans* and *M. incognita* were mutually suppressed when they coinhibited tomato roots. Reduction in *P. penetrans* population was, however, significantly greater. *P. coffeae* and *Tylenchulus semipenetrans* mutually suppressed each other on citrus (Kaplan and Timmer, 1982). Sheela and Venkitesan (1981) observed mutual suppression of *Radopholus similis* and *M. incognita* on black pepper in greenhouse experiments.

Some reports suggest that interaction between sedentary and migratory endoparasites are not always negative. They may be neutral or stimulatory. Johnson and Nusbaum (1970) observed increase in reproduction of *P. brachyurus* on tobacco in the presence of *M. incognita*. *M. naasi* favourly influenced the reproduction of *P. penetrans* on creeping bentgrass (Sikora *et al.*, 1972). Prior infection by *Ditylenchus dipsaci* on root-knot resistant cultivars of alfalfa reduced the resistance to *M. hapla* (Griffin, 1972, 1980).

Interactions between sedentary endoparasites like *Heterodera* and *Meloidogyne* species or between a sedentary endoparasite *Meloidogyne* species and a sedentary semi-endoparasite *Rotylenchulus reniformis* or between two sedentary semi endoparasites like *R. reniformis* and *Tylenchulus semipenetrans* have been also studied on certain host plants (Eisenback, 1993). Sedentary endoparasites show mutually suppressive interactions because of the common feeding sites and physiological alterations. Neutral or stimulatory effects also may occur (Eisenback, 1985; Eisenback and Griffin, 1987). In greenhouse tests, Rao and Prasad (1981) observed antagonistic interaction between *Meloidogyne graminicola* and *Heterodera oryzicola* on rice after 52 days in simultaneous or sequential inoculations of seven days. No interaction was, however, observed between *M. incognita* and *H. cajani* on cowpea in the greenhouse by Sharma and Sethi (1976). Similarly *M. hapla* and *H. schachtii* showed no interaction on sugarbeet (Jatala and Jensen, 1976, 1983). Prior inoculation of *M. hapla* on sugarbeet, stimulation of *H. schachtii* occurred. Griffin and Waite (1982) studied interaction of *H. schachtii* and *M. hapla* on tomato and found that *H. schachtii* inhibited *M. hapla*. In interaction between *M. incognita* and *H. glycine* on soybean, population of *M. incognita* was suppressed in the presence of high population densities of *H. glycine* (Ross, 1964). On tomato, presence of *P. penetrans* inhibited *M. incognita acrita* (Estores and Chen 1970). Jatala and Jensen (1983), in greenhouse experiment on sugarbeet in sequential inoculations, observed that when *H. schachtii* preceded *M. hapla* it suppressed *M. hapla* but prior inoculations by *M. hapla* stimulated *H. schachtii*.

Singh (1976) studied the interaction of *M. incognita* and *R. reniformis* on soybean in greenhouse experiments. In simultaneous inoculations *M. incognita* suppressed *R. reniformis* but *M. incognita* was not affected. Similar suppression of *R. reniformis* by *M. incognita* was observed by Mishra and Gaur (1982) on black gram (*Vigna mungo*).

Rao and Seshadri (1981) obtained antagonistic interaction between *M. incognita* and *R. reniformis* on grape seedlings. *M. incognita* was found to be more competitive. Khair and Osman (1977) and Winto and Lim (1972) showed that *R. reniformis* adversely affected *M. incognita* on tomato. Taha and Kassab (1979, 1980) showed that interaction between *M. javanica, R. reinformis* and *Rhizobium* on cowpea, *R. reniformis* suppressed the population level of *M. javanica* when it was inoculated prior to *M. javanica*. Later, *M. javanica,* however, dominated because of its high reproduction potential. No interaction between *M. javanica* and *R. reniformis* was observed on cowpea by Rao and Prasad (1971). Thomas and Clark (1980, 1981, 1983a, 1983b) studied the interaction between *M. incognita* and *R. reniformis* on sweet potato in field conditions. Low population levels of *R. reniformis* inhibited *M. incognita* whereas, *M. incognita* did not affect *R. reniformis*. High population levels of *M. incognita*, however, suppressed *R. reniformis* but *R. reniformis* had no effect on *M. incognita*. Each species appeared to be capable of suppressing the other to become the dominant species. Both low and high levels of *M. incognita* reduced the reproduction rate of *R. reniformis* but *R. reniformis* had no effect on the reproduction of *M. incognita* (Thomas and Clark, 1980, 1983a). Khan *et al.* (1985) found that concomitant inoculations of *M. incognita* and *R. reniformis* on tomato, the penetration and multiplication of *R. reniformis* were unaffected when the inoculum level of *M. incognita* was low. Increase in the inoculum level of *M. incognita* upto 100 juveniles affected multiplication of both the species but penetration was unaffected until the very high inoculum level. Khan *et al.* (1986b) observed that in concomitant inoculations of *M. incognita* and *R. reniformis* on eggplant, the multiplication rate of both species declined. The reduction was more pronounced for *M. incognita* than *R. reniformis*.

Similar trends in interactions of *M. incognita* and *R. reniformis* were obtained on tomato in artificial inoculations in greenhouse (Khan *et al.*, 1986b). No interaction occurred between *M. incognita* and *R. reniformis* on cauliflower (Khan *et al.*, 1987). No significant effects of interaction between *R. reniformis* and *Tylenchulus semipenetrans* on grape seedlings were noticed in the study of Taha and Sultan (1977). Kaplan and Timmer (1982) demonstrated that when *Pratylenchus coffeae* and *Tylenchulus semipenetrans* were together on citrus, they tended to reduce the population size of each other.

Interaction between the species of *Meloidogyne*

Meloidogyne incognita, M. javanica, M. arenaria and *M. hapla* are the major species constituting the large portion of the populations in cultivated fields (Sasser, 1982). Mixed infection on plants or infestation of crop fields is common (Khan and Khan, 1991a, 1996). Since the feeding sites of *Meloidogyne* species are same, theoretically, two or more cohabiting species may interact and it is likely that one may dominate and affect the population density of other species. But according to Eisenback (1985) their simultaneous occurrence in mixed population in the same field, root system or gall indicates that competition among the species is weak. Other factors, particularly temperature are important in the domination of a particular species. Studies on interaction between the species of *Meloidogyne* are relatively very few.

Chapman (1965) showed that interaction between *Meloidogyne incognita* and *M. hapla* was influenced by temperature. At high temperature *M. incognita* significantly dominated over *M. hapla* and 90% of the females were of *M. incognita* and only 10% were of *M. hapla*. But this ratio was changed at low temperatures and only 51% of females were of *M. incognita*. Johnson and Nusbaum (1970) observed suppressive effect of *M. incognita* over *M. hapla* on 'NC 95' and 'NC 2512' cultivars of tobacco. *M. incognita* inhibited reproduction and population of *M. hapla*. Kinloch and Allen (1972) noticed that *M. javanica* predominated over *M. hapla* in a mixed species infection on tomato at 20°C . Predominance of *M. javanica* increased with increasing the inoculum levels of both the species. Invasion by *M. hapla* was more density dependent than *M. javanica*.

M. javanica and *M. incognita* are the two most common species in tropical and sub-tropical regions of the world. They have more or less similar ecological requirements and thrive together in many different parts of world. Some recent studies (Khan *et al.*, 1984; Khan and Khan, 1985, 1990a, 1996; Haider and Khan, 1986; Khan, 1988; Haider, 1989; Khan and Haider, 1991b; Khan *et al.*, 1993, 1994) indicate that *M. javanica* and *M. incognita* are most frequent species, and are found in mixed populations in Uttar Pradesh (India). A species population may have a mixture of host races.

Interactions between different species of plant parasitic nematodes differing in their modes of parasitism have been studied (Norton, 1978; Khan, 1981; Khan, 1984; Eisenback, 1985; Eisenback and Griffin, 1987; Khan and Khan, 1988). Results of such studies show that population of one or the other species of interacting nematodes is increased or decreased. A few attempts to study interactions between the species of *Meloidogyne* have, however been made (Chapman, 1965; Johnson and Nusbaun 1970; Kinloch and Allen, 1972). Since the establishment of races in some species of *Meloidogyne*, only few studies on interaction of races of *Meloidogyne* spp. on crop plants have been studied (Haider, 1989; Haider and Khan, 1991b). The synergistic or antagonistic relationship that may develop between different species of *Meloidogyne* and races in mixed populations need to be investigated. However, more studies are needed to obtain the clear picture of interactions between species and races of root-knot nematodes because of common features in their life cycle and parasitism. In the present study, interactions between two races of *M. incognita* (races 1 and 2) and *M. javanica* (races A and B), the two most common species in the study area, have been investigated.

MATERIALS AND METHODS

Interaction

Meloidogyne javanica and *M. incognita* were found to be the two common species of root-knot nematodes in the area and they were frequently encountered in mixed populations. Among the races of *M. incognita,* races 1 and 2 were more common in occurrence than races 3 and 4 in the area. Analysis of *M. javanica* populations showed variations in host preferences and two races viz. race A and B were differentiated. In this section, interactions of *M. javanica* races (races A and B) and two races of *M. incognita* (races 1 and 2) were studied separately in artificial inoculations in glasshouse conditions.

(a) Plant Culture

Five seeds of okra cv. Pusa Sawani were directly grown in clay pots (9") containing 1Kg steam sterilized soil (soil + sand + farmyard manure in ratio of 2:1:1). After two weeks,thinning was done to retain only one seedling in each pot. Later on three-week-old seedlings were inoculated with freshly hatched second stage juveniles of the nematodes.

(b) Inoculations

Freshly hatched second stage juveniles (J2) of *M. javanica* race x and *M. incognita* race x for inoculations were obtained by incubating egg masses of the race obtained from roots of tomato or eggplant maintaining single egg mass populations. Egg masses were incubated in sterilized distilled water in petridishes (7cm in diam.) in the incubator at 25°C. After 72 hours, number of hatched juveniles (J2) were collected in water suspension. Their numbers/ml were standardized by counting the juveniles from ten, 1 ml samples of the suspension and calculating the average. Pots containing seedlings of okra (one seedling/pot) were inoculated according to the following scheme, by adding the measured quantity of the juvenile suspension with the help of pippette in depressions made in soil around the seedling.

T1	=	Control (Uninoculated)			
T2	=	*M. javanica* race	x*	1000	J2/pot
T3	=	*M. javanica* race	x	2000	J2/pot
T4	=	*M. incognita* race	x	1000	J2/pot
T5	=	*M. incognita* race	x	2000	J2/pot
T6	=	*M. javanica* race	x	1000	J2 +
		M. incognita race	x	1000	J2/pot

race x* = race A or race B of *M. javanica* or race 1 or race 2 of *M. incognita.*

Each treatment was replicated five times. After inoculations pots were maintained in glasshouse (temp. 25°C ± 2) for 50 days and watered regularly.

(c) Parameters

At termination, 50 days after inoculation, shoot length, fresh and dry weights of shoot, gall index (GI), egg mass index (EMI), soil population (J2 and male), and root population (J2 + J3/J4 + mature females) and population of females of both species were determined.

Shoot length of plants in different treatments were measured and mean of replicates were calculated. Plant shoots in different treatments were weighed to determine their fresh weight and thenafter the shoots were dried at 60°C wrapped in blotting sheets, in a hot air oven for 72h and dry weights of shoots for different treatments were determined. GI and EMI in different treatments were rated on 0-5 scale of Taylor and Sasser (Taylor and Sasser, 1978).

Soil population of nematodes (J2 and males) in each treatment was estimated by modified Cobb's sieving and decanting method (Southey, 1986). Total soil population was estimated by counting the nematodes in the suspension obtained from isolation.

For estimating root population of the nematodes (J2+J3/J4+mature females), root from each replicate weighed and cut into small pieces. One gram of the root pieces stained with acid fuchsin and lactophenol was examined under stereoscopic microscope and numbers of J2+J3/J4 were counted. Then the total number of J2+J3/J4 for the whole root system of the replicate was calculated. For counting the number of females 1g of root pieces were transferred in 5% HNO_3 and incubated at 25°C. After 72h root pieces were gently teased to release the females (Khan and Haider, 1991a, 1991b). The number of females/g of root was counted and total number of females for the whole root system was later calculated. In treatments with mixed species inoculation (*M. javanica* race x and *M. incognita* race x), the females were released by treating 1g root pieces with 5% HNO_3 and spread in petridish. Their total number was then counted. Thenafter, 15 females were randomly sampled and their perineal patterns were prepared and species were identified. The ratio of *M. javanica* race x and *M. incognita* race x in 15 females was thus established and from this value the ratio of females in the total number of females was determined.

Plant damage potential

For making a comparative assessment of the plant damage potential of races A and B of *M. javanica* and races 1 and 2 of *M. incognita*, an experiment was conducted on okra under glasshouse conditions in pots.

(a) Plant culture

Seedlings of okra cv. Pusa Sawani was raised as mentioned in interaction experiment A(a).

(b) Inoculations

Three-week-old seedlings of okra in five replicate pots (one seedling/pot) were inoculated by adding juvenile suspension of each nematode race in pots designated to receive the inoculum. The inoculum level of each nematode was invariably 5000J2/pot. Pots with seedlings without inoculations served as control. All the pots were kept at glasshouse benches (25°C±2).

(c) Parameters

At termination, after 50 days following parameters were considered.

1. Length and fresh and dry weights of shoot.
2. Gall index (GI) and egg mass index (EMI)
3. Population of females, total population and reproduction factor.

RESULTS

Interaction of races A and B of *M. javanica* with races 1 and 2 of *M. incognita* were studied separately in artificial inoculations on okra cv. Pusa Sawani.

Interaction between *M. javanica* race A and *M. incognita* race 1

(a) Shoot growth, root galling and egg mass production

M. javanica race A and *M. incognita* race 1, in single or concomitant inoculations reduced plant growth of okra cv. Pusa Sawani at both the inoculum levels when compared to uninoculated (control) plants. Okra seedlings inoculated with either 1000J2 or 2000 J2 of *M. javanica* race A or *M. incognita* race 1, showed significant suppression in all the considered growth parameters (length, fresh and dry weights) at P=0.05. Significant reduction (P=0.05) also occurred in all growth parameters in concomitant inoculation with both the races (Pi = 1000 J2 of *M. javanica* race A + 1000 J2 of *M. incognita* race 1). Reductions obtained with 1000 J2 or 2000 J2 of *M. javanica* (race A) or *M. incognita* race 1 in single inoculations were not significantly different from those obtained in concomitant inoculations (Pi = 1000 J2 of each nematode species). The reduction in growths obtained with 1000 J2 or 2000 J2 of each nematode species also did not differ significantly. *M. javanica* race A caused greater reductions in growth parameters than *M. incognita* race 1 at both the inoculum levels in single species inoculation. The per cent reduction in concomitant inoculation (Pi=1000 J2 of each) were less than single inoculation of either species at the same inoculum levels (Pi = 2000 J2) (Table 1).

In concomitant inoculation mean gall index (GI) and mean egg mass index (EMI) were reduced when compared to single inoculation at the same inoculum levels. The mean GI and EMI both for *M. javanica* race A were 4.50 and for *M. incognita* race 1, 4.5 and 4.0, respectively. In concomitant inoculation, however, mean GI and EMI were 4.0 and 3.50, respectively (Table 1).

(b) Population of females, total population and reproduction factor

The number of mature females and total population of *M. javanica* race A and *M. incognita* race 1 were reduced in their concomitant presence on the same root system as compared to their single inoculations at same levels (Pi = 2000 J2). In single species inoculation with 2000 J2, the numbers of mature females of *M. javanica* race A were 952 and *M. incognita* race 1 875. In the concomitant inoculation (Pi = 1000 J2 of *M. javanica* race A + 1000 J2 of *M. incognita* race 1), the number of females irrespective of the species were reduced to 838. This reduction to 838. This reduction was significant at P = 0.05. In total females developed in their concomitant inoculation, females of *M. javanica* race A were greater in number than *M. incognita* race 1. Out of 838 females recovered, 490 were of *M. javanica* race A and 348 of *M. incognita* race 1. When these numbers were compared with the number of females recovered from single inoculation with 1000 J2 of both the species, there was significant reduction (P=0.01). The per cent reduction in number of females of *M. incognita* race 1 (45.63%) was greater than those of *M. javanica* race A (30.00%) (Table 2). In their concomitant presence reduction in total population (soil + root) also occurred. In concomitant inocualtion of the species the total nematode population was 1392 in contrast to 1757 of *M. javanica* race A and 1551 of *M. incognita* race 1 in single species inoculation at the same inoculum level (Pi = 2000 J2). This decrease in total population was significant at P = 0.05 when compared to *M. incognita* race 1 and at both P = 0.05 and P = 0.01

Table 1. Interspecific interaction between *Meloidogyne javanica* race A (MjR_A) and *Meloidogyne incognita* race 1 (MiR_1) on okra (cv. Pusa Sawani): shoot growth, gall index (GI) and egg mass index (EMI)

Inoculation (Single+Concomitant)	Inoculum level Pi	Shoot growth			GI (mean)	EMI (mean)
		Length (cm)	Fresh weight (g)	Dry weight (g)		
Uninoculated (control)	00	32.45	23.61	8.57		
M. javanica Race A	1000	30.04* (7.42)	22.23* (5.84)	7.32* (14.58)	3.50	4.50
	2000	28.46* (12.30)	21.85* (7.45)	7.36* (14.72)	4.50	4.50
M. incognita Race 1	1000	30.14* (7.12)	22.31* (5.52)	7.58* (11.55)	3.00	3.00
	2000	28.77* (11.52)	21.95* (7.03)	7.23* (15.64)	4.50	4.00
MjR_A + MiR_1	1000 + 1000	28.74* (11.43)	21.99* (6.86)	7.29* (14.94)	4.00	3.50
L.S.D. P = 0.05		2.294	0.855	0.792		

Each value is mean of 5 replicates.
Values in parentheses in all the columns per cent represent reduction over control.
*Values are significant at P = 0.05 over control.
Pi = Initial population.

when compared to *M. javanica* race A. Accordingly, Rf value (reproduction factor) was also significantly (P = 0.05) reduced in concomitant inoculation of the species in comparison to single species inoculation at the same inoculum level (Table 2).

Interaction between *M. javanica* race A and *M. incognita* race 2

(a) Shoot growth, root galling and egg mass production

M. javanica race A and *M. incognita* race 2 singly or concomitantly reduced plant growth of okra plants. When okra seedlings were inoculated with either 1000 J2 or 2000 J2 of *M. javanica* race A or *M. incognita* race 2, significant reduction occurred in all the growth parameters (length fresh and dry weights) at P = 0.05. In their concomitant inoculation with 1000 J2 of each (Pi = 1000 J2 of *M. javanica* race A + 1000 J2 of *M. incognita* race 2) significant reductions (P = 0.05) in growth parameters were also recorded. The reductions obtained with 1000 J2 or 2000 J2 of *M. javanica* race A and *M. incognita* race 2 in their single inoculation and concomitant inoculation were statistically similar. The per cent reductions in growth parameters were greater for *M. javanica* race A than *M. incognita* race 2 at both inoculum levels in single species inoculations. The per cent reduction in concomitant inoculation (Pi = 1000 J2 of each) were less than single inoculation of either species at the same inoculum levels (Table 3). Mean GI and EMI of *M. javanica* race A in single species inoculation (Pi = 2000 J2) were 5.0. For *M. incognita* race 2, mean GI and EMI both were 4.50. In concomitant inoculation of both the species, mean GI and EMI were reduced. These were 4.5 and 4.0 respectively (Table 3).

(b) Population of females, total population and reproduction factor

The numbers of mature females and total population of *M. javanica*

Table 2. Interspecific interaction between *Meloidogyne javanica* race A (MjR_A) and *Meloidogyne incognita* race 1 (MiR_1) on okra (cv. Pusa Sawani): population of females, total population and reproduction factor

Inoculation (Single + Concomitant)	Inoculum level Pi	Soil population		Root population		Total population Pf)	Reproduction factor (Rf)	No. of females	
		J2	Male	(J2+J3+J4)	Mature female			MjR_A	MiR_1
M. javanica Race A	1000	475	42	56	700	1273	1.27	700	-
	2000	643	64	98	952	1757	0.88	952	-
M. incognita Race 1	1000	330	29	49	640	1048	1.08	-	640
	2000	548	56	82	875	1551	0.77	-	875
MjR_A + MiR_1	1000+1000	450	40	64	838*	1392*	0.69*	490** (30.00)[a]	348** (45.63)[a]
L.S.D. P = 0.05					625.44	80.56	0.043	148.4	159
P = 0.01					35.04	110.96	0.876	204.4	219

Each value is mean of 5 replicates.

* and ** Values are significantly different at P = 0.05 and at both P = 0.05 and 0.01 respectively from single species inoculation with the same inoculum level.

a = Values represent per cent reduction.

Pi = Initial population; Pf = Final population.

Table 3. Interspecific interaction between *Meloidogyne javanica* race A (MjR_A) and *Meloidogyne incognita* race 2 (MiR_2) on okra (cv. Pusa Sawani): shoot growth, gall index (GI) and egg mass index (EMI)

Inoculations (Single+Concomitant)	Inoculum level Pi	Shoot growth			GI (mean)	EMI (mean)
		Length (cm)	Fresh weight (g)	Dry weight (g)		
Uninoculated (control)	00	33.72	23.76	8.98		
M. javanica Race A	1000	31.20* (7.47)	22.39* (5.77)	7.66* (14.70)	4.00	4.00
	2000	29.43* (12.22)	22.02* (7.32)	7.33* (18.37)	5.00	5.00
M. incognita Race 2	1000	31.36* (7.00)	22.47* (5.43)	7.73* (13.92)	3.50	3.50
	2000	30.01* (11.00)	22.21* (6.52)	7.54* (16.04)	4.50	4.50
MjR_A + MiR_2	1000 + 1000	30.15* (10.58)	22.33* (6.02)	7.62* (15.14)	4.50	4.00
L.S.D. P= 0.05		1.919	0.876	0.750		

Each value is mean of 5 replicates.
Values in parentheses in all the columns represent per cent reduction over control.
*Values are significant at P = 0.05 over control.
Pi = Initial population.

race A and *M. incognita* race 2 were reduced when both were concomitantly present on the same root system. The numbers of mature females of both the species also mutually declined. In single species inoculation with 2000 J2, the numbers of mature females of *M. javanica* race A were 1009 and *M. incognita* race 2, 936 but in their concomitant inoculation with 2000 J2 (Pi=1000 J2 of *M. javanica* race A + 1000 J2 of *M. incognita* race 2), the number of females irrespective of the species was significantly (P = 0.05) reduced to 855. Female of *M. javanica* race A were greater in number than *M. incognita* race 2. Out of 855 total females population, 455 belonged to *M. javanica* race A and 300 to *M. incognita* race 2. These numbers were significantly reduced (P = 0.01) as compared to the number of females recovered from single inoculation with 1000 J2 of the species. Decline in number of females of *M. incognita* race 2 (48.10%) was greater than those of *M. javanica* race A (28.35%) (Table 4).

Reduction in total population (soil + root) in their concomitant inoculation also occurred. The total nematode population was 1475 in contrast to 1831 of *M. javanica* race A and 1727 of *M. incognita* race 2 in single species inoculation at the same inoculum level (Pi = 2000 J2). This decrease in total population was significant at P = 0.05 and P=0.01 when compared to both *M. incognita* race 2 and *M. javanica* race A. Accordingly, Rf value was also less (P = 0.05) in concomitant inoculation of the species than in single species inoculation at the same inoculum level (Table 4).

Interaction between *M. javanica* race B and *M. incognita* race 1

(a) Shoot growth, root galling and egg mass production

M. incognita race 1 and *M. javanica* race B singly or

Table 4. Interspecific interaction between *Meloidogyne javanica* race A (MjR_A) and *Meloidogyne incognita* race 2 (MiR_2) on okra (cv. Pusa Sawani): population of females, total population and reproduction factor

Inoculation (Single + Concomitant)	Inoculum level Pi	Soil population J2	Soil population Male	Root population (J2+J3+J4)	Root population Mature female	Total population (Pf)	Reproduction factor (Rf)	No. of females MjR_A	No. of females MiR_1
M. javanica Race A	1000	445	32	36	635	1148	1.15	635	-
	2000	675	72	75	1009	1831	0.92	1009	-
M. incognita Race 2	1000	364	30	31	578	1003	1.00	-	578
	2000	653	68	70	936	1727	0.86	-	936
$MjR_A + MiR_2$	1000+1000	594	62	64	855*	1475**	0.74*	455** (28.35)[a]	300** (48.10)[a]
L.S.D. P = 0.05					50.64	129.32	0.106	108.12	159
P=0.01					70.08	178.12	0.146	148.92	219

Each value is mean of 5 replicates.

* and ** Values are significantly different at P = 0.05 and at both P=0.05 and 0.01 respectively from single species inoculation with the same inoculum level.

a = Values represent per cent reduction.

Pi= Initial population. Pf=Final population.

concomitantly reduced plant growth of okra cv. Pusa Sawani when compared to uninoculated (control) plants. Either nematode at 1000 J2 or 2000 J2 caused significant reduction in all the growth parameters (length, fresh and dry weights) (P=0.05). In their concomitant inoculation with 1000 J2 of each (Pi = 1000 J2 of *M. incognita* race 1 + 1000 J2 of *M. javanica* race B) significant reductions (P = 0.05) in growth parameters were also recorded. The reductions obtained with 1000 J2 or 2000 J2 of *M. incognita* race 1 and *M. javanica* race B in their single inoculation were not significantly different from reductions in their concomitant inoculations (Pi = 1000 J2 of each nematode species). The reduction in growths obtained with 1000 J2 or 2000 J2 of each nematode species also did not differ significantly. The per cent reductions in growth parameters were greater for *M. incognita* race 1 than *M. javanica* race B at both the inoculum levels in single species inoculations. The per cent reduction in concomitant inoculation (Pi=1000 J2 of each) were less than single inoculation of either species at the same inoculum levels (Pi=2000 J2) (Table 5).

In concomitant inoculation mean gall index (GI) and mean egg mass index (EMI) were reduced when compared to their single inoculations at the same inoculum levels. The mean GI and EMI both for *M. incognita* race 1 were 5.0 and for *M. javanica* race B 4.50. In concomitant inoculation, however, mean GI and EMI were 4.50 and 4.00, respectively (Table 5).

(b) Population of females, total population and reproduction factor

The number of mature females and total population of *M. incognita* race 1 and *M. javanica* race B were suppressed in their concomitant presence on the same root system. The number of mature females of *M. incognita* race 1 was 930 and *M. javanica* race B 896 but in their

Table 5. Interspecific interaction between *Meloidogyne incognita* race 1 (MiR_1) and *Meloidogyne javanica* race B (MjR_B) on okra (cv. Pusa Sawani): shoot growth, gall index (GI) and egg mass index (EMI)

Inoculations (Single+Concomitant)	Inoculum level Pi	Shoot growth			GI (mean)	EMI (mean)
		Length (cm)	Fresh weight (g)	Dry weight (g)		
Uninoculated (control)	00	29.83	24.47	8.36	-	-
M. incognita **Race 1**	1000	27.73* (7.04)	22.54* (7.88)	7.37* (11.84)	4.00	4.00
	2000	26.49* (11.20)	21.63* (11.61)	6.42* (23.21)	5.00	5.00
M. javanica **Race B**	1000	28.17* (5.56)	23.13* (5.48)	7.46* (10.77)	3.0	3.0
	2000	27.35* (8.31)	22.46* (8.21)	6.65* (20.45)	4.5	4.5
$Mi_{R1} + MjR_B$	1000 + 1000	27.42* (8.08)	22.50* (8.05)	6.84* (18.18)	4.5	4.0
L.S.D. P= 0.05		1.481	0.709	0.646		

Each value is mean of 5 replicates.

Values in parentheses in all the columns represent per cent reduction over control.

*Values are significant at P = 0.05 over control.

Pi = Initial population.

concomitant inoculation with 2000 J2 (Pi=1000 J2 of each *M. incognita* race 1 and *M. javanica* race B) the number of females irrespective of the species was reduced to 743 (P = 0.01). Females of *M. incognita* race 1 was greater in number than *M. javanica* race B. Out of 743 females, *M. incognita* race 1 had 433 and *M. javanica* race B 310. Significant reduction (P = 0.01) occurred, when these number were compared with the number of females recorded from single inoculation with 1000 J2 of the species. Reduction in number of females of *M. javanica* race B (46.09%) was comparatively greater than *M. incognita* race 1 (33.38%) (Table 6).

Reduction in total nematode population (soil + root) in their concomitant presence also occurred. In concomitant inoculation of the nematodes, total nematode population declined (P = 0.01) and it was 1472 in contrast to 1812 of *M. incognita* race 1 and 1663 of *M. javanica* race B in single species inoculation at the same inoculum level (Pi=2000 J2). Rf value was also less in concomitant inoculation of the species. (P = 0.05) (Table 6).

Interaction between *M. javanica* race B and *M. incognita* race 2

(a) Shoot growth, root galling and egg mass production

Interaction of *M. javanica* race B and *M. incognita* race 2 was also mutually suppressive. *M. incognita* race 2 and *M. javanica* race B singly or concomitantly reduced plant growth of okra cv. Pusa Sawani when compared to uninoculated (control) plants. When okra seedlings were inoculated with *M. incognita* race 2 or *M. javanica* race B, all the considered growth parameters were suppressed (P = 0.05). In their concomitant inoculation with 1000 J2 of each (Pi=1000 J2 of *M. incognita* race 2 + 1000 J2 of *M. javanica* race B) significant

Table 6. Interspecific interaction between *Meloidogyne incognita* race 1 (MiR_1) and *Meloidogyne javanica* race B (MiR_B) on okra (cv. Pusa Sawani): population of females, total population and reproduction factor

Inoculation (Single + Concomitant)	Inoculum level Pi	Soil population J2	Soil population Male	Root population (J2+J3+J4)	Root population Mature female	Total population (Pf)	Reproduction factor (Rf)	No. of females MjR_A	No. of females MiR_1
M. incognita Race 1	1000	440	40	52	650	1182	1.18	650	-
	2000	698	86	98	930	1812	0.91	930	-
M. javanica Race B	1000	427	28	37	575	1067	1.07	-	575
	2000	635	60	72	896	1663	0.83	-	896
Mi_{R1} + MjR_B	1000+1000	605	56	68	743*	1472**	0.74*	433** (33.38)[a]	310** (46.09)[a]
L.S.D. P = 0.05					59.3	95.4	0.084	110.2	101.7
P = 0.01					81.7	131.4	0.116	151.8	140.1

Each value is mean of 5 replicates.

* and ** Values are significantly different at P = 0.05 and at both P=0.05 and 0.01 respectively from single species inoculation with the same inoculum level.

a = Values represent per cent reduction.

Pi= Initial population, Pf=Final population.

reductions (P=0.05) occurred in growth parameters. The reductions with 1000 J2 or 2000 J2 of *M. incognita* race 2 and *M. javanica* race B in their single inoculation were not significantly different from reductions in their concomitant inoculations (Pi = 1000 J2 of each nematode species). The reductions in growths obtained with 1000 J2 or 2000 J2 of each nematode species also did not differ significantly. The per cent plant growth suppression was greater for *M. incognita* race 2 than *M. javanica* race B at both the inoculum levels in single species inoculations. The per cent reduction in concomitant inoculation (Pi = 1000 J2 of each) were less than single inoculation of either species at the same inoculum levels (Pi = 2000 J2) (Table 7).

Mean GI and EMI were 4.5 for both *M. incognita* race 2 and *M. javanica* race B in single species inoculation (Pi = 2000 J2). In concomitant inoculation of both the species, mean GI and EMI were reduced. These were 4.0 and 3.5, respectively (Table 7).

(b) Population of females, total population and reproduction factor

In comparison to single species inoculation with 2000 J2, the number of mature females and total populations of *M. incognita* race 2 and *M. javanica* race B were reduced in their concomitant presence (Pi = 1000 J2 + 1000 J2 of each). The number of mature females of *M. incognita* race 2 was 866 and *M. javanica* race B 813 in single inoculation while in their concomitant inoculation with 2000 J2 (Pi=1000 J2 of *M. incognita* race 2 + 1000 J2 of *M. javanica* race B), the number of females irrespective of the species was reduced to 785 (P = 0.05). *M. incognita* race 2 was greater in number than *M. javanica* race B. Out of 785 females, 428 were of *M. incognita* race 2 and 357 of *M. javanica* race B. When these numbers were compared with the number of

Table 7. Interspecific interaction between *Meloidogyne incognita* race 2 (MiR_2) and *Melodiogyne javanica* race B (MjR_B) on okra (cv. Pusa Sawani): shoot growth, gall index (GI) and egg mass index (EMI)

Inoculations (Single+Concomitant)	Inoculum level Pi	Shoot growth			GI (mean)	EMI (mean)
		Length (cm)	Fresh weight (g)	Dry weight (g)		
Uninoculated (control)	00	27.64	21.75	7.35		
***M. incognita* Race 2**	1000	25.71* (6.98)	20.51* (5.70)	6.49* (11.70)	4.0	4.00
	2000	24.76* (10.42)	19.24* (11.54)	5.63* (23.40)	4.5	4.50
***M. javanica* Race B**	1000	26.11* (5.54)	20.57* (5.43)	6.56* (10.75)	3.0	3.0
	2000	24.97* (9.66)	19.38* (10.89)	5.79* (21.22)	4.50	4.50
MiR_1 + MjR_B	1000 + 1000	25.21* (8.79)	19.54* (10.16)	5.96* (18.91)	4.0	3.50
L.S.D. P= 0.05		0.917	0.813	0.604		

Each value is mean of 5 replicates.

Values in parentheses in all the columns represent per cent reduction over control.

*Values are significant at P = 0.05 over control.

Pi = Initial population.

females recorded from single inoculation with 1000 J2 of the species, there were significant reductions at both levels (P=0.05) and (P = 0.01). Reduction in number of females of *M. javanica* race B (40.50%) was greater than those of *M. incognita* race 2 (35.15%) (Table 8).

Reduction in total nematode populations (soil + root) in their concomitant presence was also observed. The population was 1482 in contrast to 1713 of *M. incognita* race 2 and1611 of *M. javanica* race B in single species inoculation at the same inoculum level (Pi = 2000 J2). This decrease in total population was significant at P = 0.05 and P = 0.01 when compared to *M. incognita* race 2 and *M. javanica* race B. Rf value in concomitant inoculation of the species was less (Pi = 0.05) in comparison to single species inoculation at the same inoculum level (Table 8).

Plant damage potential and reproduction efficiency

Comparative plant damage potential and reproduction efficiency of races A and B of *M. javanica* and races 1 and 2 of *M. incognita* were assessed on okra cv. Pusa Sawani under glasshouse conditions in artificial inoculations.

(a) Shoot growth, root galling and egg mass production

Races A and B of *M. javanica* and races 1 and 2 of *M. incognita* (each at Pi = 5000 J2) caused significant reduction in plant growth of okra. Race A of *M. javanica* caused greater plant damage than races 1 and 2 of *M. incognita* and race B of *M. javanica*. The reduction caused by race A of *M. javanica* was significantly greater than race B of *M. javanica* and race 2 of *M. incognita* in length, dry weight (P = 0.05) and fresh weight (P = 0.01).

Among the races of *M. incognita*, race 1 caused apparently greater reduction than race 2 but differences were not significant. The

Table 8. Interspecific interaction between *Meloidogyne incognita* race 2 (MiR_2) and *Meloidogyne javanica* race B (MjR_B) on okra (cv. Pusa Sawani): population of females, total population and reproduction factor

Inoculation (Single + Concomitant)	Inoculum level Pi	Soil population		Root population		Total population (Pf)	Reproduction factor (Rf)	No. of females	
		J2	Male	(J2+J3+J4)	Mature female			MjR_A	MiR_1
M. incognita Race 2	1000	480	36	58	660	1234	1.34	660	-
	2000	694	56	97	866	1713	0.86	866	-
M. javanica Race B	1000	415	33	42	600	1090	1.09	-	600
	2000	660	50	88	813	1611	0.81	-	813
Mi_{R2} + MjR_B	1000+1000	585	42	70	785*	1482*	0.74*	428* (35.15)[a]	357* (40.50)[a]
L.S.D. P = 0.05					12.96	67.8	0.063	122.9	112.3
P = 0.01					17.52	93.4	0.087	169.3	154.7

Each value is mean of 5 replicates.

* and ** Values are significantly different at P = 0.05 and at both P=0.05 and 0.01 respectively from single species inoculation with the same inoculum level.

a = Values represent per cent reduction.

Pi= Initial population, Pf=Final population.

Table 9. Plant damage potential of races A and B of *Meloidogyne javanica* and races 1 and 2 of *Meloidogyne incognita* at the same inoculum level (5000 J2) on okra (cv. Pusa Sawani): shoot growth, gall index (GI) and egg mass index (EMI)

Meloidogyne spp.	Inoculum level (J2)	Shoot growth			GI/EMI (mean)
		Length (cm)	Fresh weight (g)	Dry weight (g)	
Uninoculated (control)	00	40.58	29.24	10.28	-
M. javanica **Race A**	5000	33.67* (17.03)	21.13 (27.74)	6.23 (38.80)	5/5
M. incognita **Race 1**	5000	34.72 (14.44)	22.36 (23.60)	6.85 (32.71)	5/5
M. incognita **Race 2**	5000	35.96 (12.84)	23.25 (20.49)	7.52 (26.13)	5/5
M. javanica **Race B**	5000	36.44 (10.20)	24.00 (17.92)	7.66 (24.75)	5/5
L.S.D. P= 0.05		1.90	1.293	1.272	
P=0.01		2.62	1.781	1.752	

Each value is mean of 5 replicates.
Values in parentheses represent per cent reduction over uninoculated (control).
*Values are significant at P = 0.05 over control.
Pi = Initial population.

Table 10. Reproduction efficiency of races A and B of *Meloidogyne javanica* and races 1 and 2 of *Meloidogyne incognita* at the same inoculum level (5000 J2) on okra (cv. Pusa Sawani): population of females, total population and reproduction factor

Inoculations (Single + Concomitant)	Inoculum level Pi	Soil population		Root population			Total population (Pf)	Reproduction factor (Rf)
		J_2	Male	J_2	J_3+J_4	Mature female		
Uninoculated (Control)	00	-	-	-	-	-	-	-
M. javanica Race A	5000	3320	87	503	204	2064	6178	1.24
M. incognita Race 1	5000	3280	79	478	194	2041	6072	1.21
M. incognita Race 2	5000	3174	72	460	183	1992	5881	1.18
M. javanica Race B	5000	3050	68	435	166	1937	5656	1.13
L.S.D. P = 0.05						53.0	190.8	0.042
P = 0.01						73.0	262.8	0.058

Each value is mean of 5 replicates.

* and ** Values are significantly different from *M. javanica* at P = 0.05 and at both P=0.05 and 0.01 respectively.

a = values represent per cent reduction.

Pi= Initial population. Pf=Final population.

damages caused in shoot growth by the nematodes were in the following order: *M. javanica* race A > *M. incognita* race 1 > *M. incognita* race 2 > *M. javanica* race B.

Root galling and egg mass production of the nematodes on this cultivar of okra did not show variation when rated for gall index (GI) and egg mass index (EMI). Mean GI and EMI were invariably 5.0 for all the test nematodes, (Table 9).

(b) Population of females, total population and reproduction factor

Population of mature females, total population and reproduction factor of the nematodes showed variations. The highest number of mature females were recovered from the roots inoculated with *M. javanica* race A followed by *M. incognita* race 1, *M. incognita* race 2 and *M. javanica* race B. The difference between the numbers of females of *M. javanica* race A and *M. incognita* race 1 was not significant. *M. javanica* race A, however, produced significantly greater (P = 0.05) number of females than *M. incognita* race 2 and *M. javanica* race B. The total population was highest for *M. javanica* race A. It was greater than *M. incognita* race 2 and race B of *M. javanica* but not race 1 of *M. incognita* (P = 0.05). Total population of *M. incognita* race 1 was significantly greater (P = 0.05) than race 2 of *M. incognita* and *M. javanica* race B (Table 10).

Reproduction factor of the nematodes also varied accordingly. The Rf value was highest for *M. javanica* race A and it was significantly greater (P = 0.05) than *M. incognita* race 2 and *M. javanica* race B, but not significantly different from race 1 of *M. incognita*. Among the races of *M. incognita*, Rf value of race 1 was higher than race 2. (Table 10).

DISCUSSION

A number of climatic and edaphic factors, cropping history, host suitability, reproductive efficiency, persistence and interactions with other organisms including nematodes determine survival and relative success of individual nematode species in mixed species communities (Oostenbrink, 1966; Norton, 1978; Eisenback, 1985). Interaction between two nematodes species may be suppressive to one or both species (antagonistic), have no effect (neutral) or benificial to one or both speices (mutualistic) These effects are generally related to the mode of parasitism. Competition between species with similar modes of parasitism is more intense than the species with dissimilar feeding habits. Interaction between sedentary endoparasites, are generally mutually suppressive as the competition between the species is for the same feeding sites to induce similar histopathological and physiological alterations in the hosts.

The findings of the present studies on interspecific interactions of races A and B of *M. javanica* with races 1 and 2 of *M. incognita,* has shown that *M. javanica* race A had better competitive ability than races 1 and 2 of *M. incognita* and race B of *M. javancia.* (Table 1-8). Interaction between *M. javanica* race A and *M. incognita* race 1 was antagonistic in causation of plant growth suppression. *M. javanica* race A and *M. incognita* race 1 concomitantly at Pi = 2000 J2 (Pi = 1000 J2 of each) caused less reductions in shoot growth of plants as compared to their single species inoculation (Pi = 1000 J2 of each) of plants. The root galling and egg mass production of each species, were mutually suppressive and number of mature females and total population and reproduction factor of nematodes were reduced in their concomitant presence on same root system. The reduction in number of females of *M. incognita* race 1 was greater than *M. javanica* race A. Consequently total population in concomitant inoculation of the species, the reproduction factor of the nematodes showed decline. This indicated that negative interaction (antagonistic) occurred between *M. javanica* race A and *M. incognita* race 1. Both the nematodes were mutually suppressive, which adversely affected root galling, egg mass production, total number of females, total population and reproduction factor of each other. This mutually suppressive effects of the species were benificial for the plant growth. The similar results have also been observed in earlier studies, where host plants were found to derive benifit from mutually inhibitory interactive effects of interacting nematodes species and showed better growth (Wallace, 1978; Eisenback, 1985; Khan *et al.*, 1986a, 1986b; Eisenback and Griffin, 1987). This effect was observed becasue both species have similar modes of parasitism and feeding sites. Reproduction efficiency of each was affected adversly by the presence of the other species. Such reductions in reproduction efficiency of the nematodes may have little effect on the plant growth in experimental conditions or during a single growing season. But it would affect the inoculum potential which may have significant ecological implication in field conditions during successive cropping seasons. The interactive effects of *M. javanica* race A was more inhibitory than *M. incognita* race 1 in their antogonistic relationship. *M. javanica* race A developed more females than *M. incognita* race 1 and showed greater plant damage potential. A similar pattern in mutual inhibitory effects was noticed in the interactions between *M. javanica* race A and *M. incognita* race 2; between *M. incognita* race 1 and *M. javancia* race B; and between *M. incognita* race 2 and *M. javanica* race B.

Among the two designated races, *M. javanica* race A is apparently more damaging than race B or races 1 and 2 of *M.*

incognita. M. incognita races 1 and 2 formed more females than race B of *M. javanica* in their interactions. The suppressive affects of *M. javanica* race A was greater on race 2 of *M. incognita* than race 1 of *M. incognita.* Race 2 of *M. incognita* and race B of *M. javanica* caused relatively less inhibitory effect on female production than race 1 of *M. incognita* and race A of *M. javanica.* Hence, it can be surmized that in a mixed community, *M. javanica* race A has better capacity for competition than others. Race 1 of *M. incognita* has also better attributes in these respects than race 2 of *M. incognita* and race B of *M. javanica.*

The interaction studies between *R. reniformis* and *Meloidogyne* species also exhibited varying interaction effects. Mutual suppression on grape seedlings (Rao and Sheshadri, 1981), suppression of *R. reniformis* alone on soybean and black gram (Singh, 1976; Mishra and Gaur, 1982), suppression of *M. incognita* on tomato (Kheir and Osman, 1977; Winto and Lim, 1972; Khan *et al.*, 1986a) and on eggplant (Khan *et al.*, 1986b) have been observed in their interactions. The importance of initial population and host suitability in interactions between *M. incognita* and *R. reniformis* has also been demonstrated (Thomas and Clark, 1980, 1981, 1983b; Khan, *et al.*, 1986a, 1986b, 1987). The initial population density and competition for food and space are important factors which determine the rate of population growth in a multiple species nematode populations and interactive effects on the interacting species. Mode of parasitism and host efficiency are other important contributing factors (Norton, 1978; Khan, 1984).

In interaction between the species of *Meloidogyne* predominance of *M. javanica* over *M. hapla* has been shown (Kinloch and Allen, 1972). Reproduction and population of *M. hapla* were inhibited by *M. incognita* on tobacco cultivar. (Johnson and Nusbaum, 1970). Importance of temperature in the relative dominance of *Meloidogyne* spp. particularly *M. incognita* and *M. hapla* has been demonstrated (Johnson and Nusbaum, 1970). Temperature is regarded as most important for regulating the distribution of *Meloidogyne* species because some species are more common in cooler climates and others are better adapted to warmer climates (Taylor *et al.*, 1982; Eisenback and Griffin, 1987). This feature has been evident from the results on the distribution of the species in the present study (Section I).

In natural conditions, other factors as well may influence the interactions between *Meloidogyne* species and the interactive effect depending upon the species involved. Both *M. incognita* and *M. javanica* are sedentary endoparasites and their host parasitic relationships are identical. They have same zones of penetration and feeding sites in host roots. Possibly relative differences displayed by the species and race in relation to plant damage potential and reproduction efficiency, were responsible for the interactive effects on the nematodes. When races 1 and 2 of *M. incognita* and races A and B of *M. javanica* were varied on a given host under the same controlled environmental factors (atmospheric and edaphic) under glasshouse conditions, variations in their damage potential (reductions in plant growth) and reproduction efficiency (population of females) existed. *M. javanica* race A appeared as most efficient followed by race 1, race 2 of *M. incognita* and race B of *M. javanica* in the given experimental conditions. Race B of *M. javanica* was poorest among the nematodes in these respects. These attributes of *M. javanica* race A and *M. incognita* race 1, may be responsible for their relative dominance, and frequent occurrence.

It has been generalized that the species of nematodes can co-inhabit even living in close proximity influencing each other directly or indirectly (Norton, 1978) and one population can not exclude the other as required by the Gause's principle. The results of the present study corroborate it. At the same time, it also supports the contention that competition among the species of *Meloidogyne*, particularly between *M. javanica* and *M. incognita* is weak as stated by Eisenback (1985). Though the antagonistic interactions between *M. javanica* and *M. incognita* were not very intense, such interactions may be occurring in nature, influencing their reproduction efficiency and population growth. But the species manage to co-exist.

SUMMARY

Interspecific interaction of races A and B of *M. javanica* with races 1 and 2 of *M. incognita* were studied separately in artificial inoculations on okra cv. Pusa Sawani. Mutually inhibitory interaction occurred between *M. javanica* and *M. incognita*, regardless of races involved. The races of *M. javanica* and *M. incognita* singly or concomitantly, caused significant reduction in plant growth of okra. The reductions in plant growth caused by single species inoculation at Pi 1000 or Pi 2000 J2 of the species were not significantly different in general. Reduction in plant growth caused by *M. javanica* race A was highest followed by *M. incognita* race 1, *M. incognita* race 2 and *M. javanica* race B. Apparently the reduction in plant growth of concomitant inoculation was less as compared to any race at the same inoculum level. The interspecific interaction of race A and race B of *M. javanica* with race 1 and race 2 of *M. incognita* influenced the root galling and egg mass production. The mean GI and EMI values were reduced in their concomitant presence. Number of mature females, total population and reproduction factor of each species, irrespective of races were reduced in concomitant inoculations. The species mutually suppressed each other when present on the same root system. The reductions in number of mature females/root system of race 1 and race 2 of *M. incognita* were greater than *M. javanica* race A but less than *M. javanica* race B.

Among the races of *M. incognita* and *M. javanica,* the per cent reductions were lowest for *M. javanica* race A (28.35%), followed by *M. incognita* race 1 (33.38%), *M. incognita* race 2 (35.15%) and *M. javanica* race B (40.50%) in this order.

The interaction of races A and B of *M. javanica* and races 1 and

2 of *M. incognita* also influenced the total population of the nematodes. The total population was reduced by their concomitant presence when compared to the total population obtained in single species inoculation of *M. javanica* race A and race B or either race 1 and race 2 of *M. incognita* at the same level. The Rf value also declined in their interactions.

Among the races of *M. javanica* and *M. incognita*, race A of *M. javanica* was more damaging than the race B. Race 1 caused apparently greater reduction than race 2 of *M. incognita*. But the reductions were statistically not different. The highest number of mature females was produced by *M. javanica* race A, followed by *M. incognita* race 1, *M. incognita* race 2 and *M. javanica* race B. The total population was also highest for *M. javanica* race A, followed by *M. incognita* race 1, *M. incognita* race 2 and *M. javanica* race B. A similar trend was also observed in reproduction factor.

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